HIGHWAY RESEARCH REPORT

DYNAMIC TESTS OF THE MODIFIED CALIFORNIA TYPE 20 BRIDGE BARRIER RAIL

SERIES XXVIII

STATE OF CALIFORNIA

BUSINESS AND TRANSPORTATION AGENCY

DEPARTMENT OF PUBLIC WORKS

DIVISION OF HIGHWAYS

MATERIALS AND RESEARCH DEPARTMENT

RESEARCH REPORT

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16. ABSTRACT

The results of seven vehicle impact tests into the Modified California Type 20 Bridge Barrier Rail are reported. The Modified Type 20 bridge rail is a rigid system which features a 20 inch high reinforced lightweight concrete "Safety Shape" parapet. A 2 x 6 by 1/4 inch structural steel tube rail is mounted 12 inches above the parapet on fabricated steel posts. The overall barrier height is 32 inches.

Tests were conducted at impact velocities and approach angles ranging from approximately 46 mph/5 deg. to 72 mph/25 deg. Test results indicate that the Modified Type 20 design will redirect a passenger vehicle impacting at up to 65 mph/15 degrees. The resulting vehicle damage is more severe than that sustained in similar impacts of the standard Type 20 design. The lightweight concrete parapet was neither structurally or geometrically adequate to retain the test vehicle impacting at 72 mph/25 degrees. It was therefore concluded that the modified Type 20 design tested in this study was less effective than the standard Type 20 design.

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STATE OF CALIFORNIA—BUSINESS AND TRANSPORTATION AGENCY

RONALD REAGAN, Governor

DEPARTMENT OF PUBLIC WORKS
DIVISION OF HIGHWAYS
MATERIALS AND RESEARCH DEPARTMENT
5900 FOLSOM BLVD., SACRAMENTO 95819

December 1972
Final Report
M&R No. 636589
D-4-97

Mr. R. J. Datel
State Highway Engineer

Dear Sir:

Submitted herewith is a research report titled:

DYNAMIC TESTS

OF THE

MODIFIED CALIFORNIA TYPE 20 BRIDGE BARRIER RAIL

SERIES XXVIII

Principal Investigators

J. R. Stoker, R. P. Hackett, and R. N. Doty

Principal Assistant

R. A. Pelkey

Under the General Direction of

Eric F. Nordlin

Very truly yours,

JOHN L. BEATON
Materials and Research Engineer

ACKNOWLEDGEMENTS

This work was accomplished in cooperation with the United States Department of Transportation, Federal Highway Administration, as Item D-4-97 of Work Program HPR-PR-1(8), Part 2, Research. The contents of this report reflect the views of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the State of California or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

The dedication and competence of the following staff members of the Materials and Research Department made the successful testing described herein possible:

1. Roger Stoughton, Orvis Box, and Lee Staus assisted in the barrier construction and the test site preparation, instrumented the test vehicle, conducted the tests, and assisted with the data analysis and preparation of this report.

2. William Chow, Richard Johnson, Stanley Law, and Delmar Gans calibrated the test vehicle and dummy instrumentation, assembled and operated the data acquisition and processing systems, and assisted in the interpretation of the data obtained with these electronic systems.

3. Robert Mortensen and Lewis Green provided both data and documentary photographic coverage of the tests.

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I. INTRODUCTION

The California Type 20 Bridge Barrier Rail, designed by the California Division of Highways Bridge Department, was proven effective in a test series conducted in 1969[1]. That barrier is shown in Figure 1.

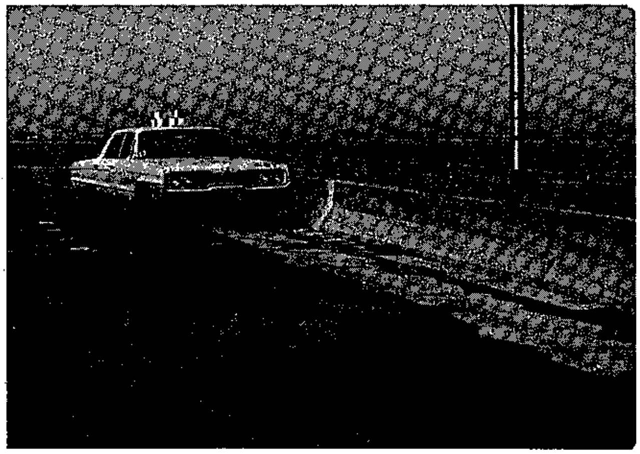


FIGURE 1 - CALIFORNIA TYPE 20 BRIDGE BARRIER RAIL - TEST BARRIER

The Type 20 Bridge Barrier Rail was patterned after the New Jersey concrete median barrier, which was evaluated by the California Division of Highways in 1967[2], and a subsequent bridge rail developed by General Motors[3]. The Type 20 design incorporates a 27-inch high concrete parapet with a single steel rail mounted 12-inches above the parapet on fabricated steel posts. The traffic-side profile of the parapet is almost identical to that of the New Jersey barrier. This "safety shape" contour, which slopes the face of the parapet away from traffic, is designed to lift and turn an impacting vehicle parallel with the barrier, thus minimizing vehicular damage, particularly at the more prevalent flat angles of impact. The details of various highway barriers with concrete parapets, including the Type 20 and the Modified Type 20, are comparatively shown in Figure 2. Although the Type 20 parapet was higher than other bridge rail parapets in use in California, it was felt that the added height was necessary for the barrier to be effective. The Modified Type 20 design was subsequently proposed in the hopes that a lower parapet, while providing improved sight distance and a more aesthetically pleasing bridge, would also effectively re-direct an impacting vehicle. When viewed from a distance, a lower concrete parapet makes the entire bridge deck appear more slender and graceful.

The Modified Type 20 Bridge Rail design was developed with the same steel post/railing system and "safety shape" concrete parapet of the standard Type 20 design. However, the concrete parapet height was reduced from 27 inches to 20 inches. The effect that this reduction in parapet height would have on vehicular response and damage was a prime test parameter. The other main factor to be evaluated was the use of lightweight concrete in the bridge deck and barrier rail parapet. A series of seven full scale vehicle impact tests were conducted at varying impact speeds and approach angles. The results of those tests are contained herein.

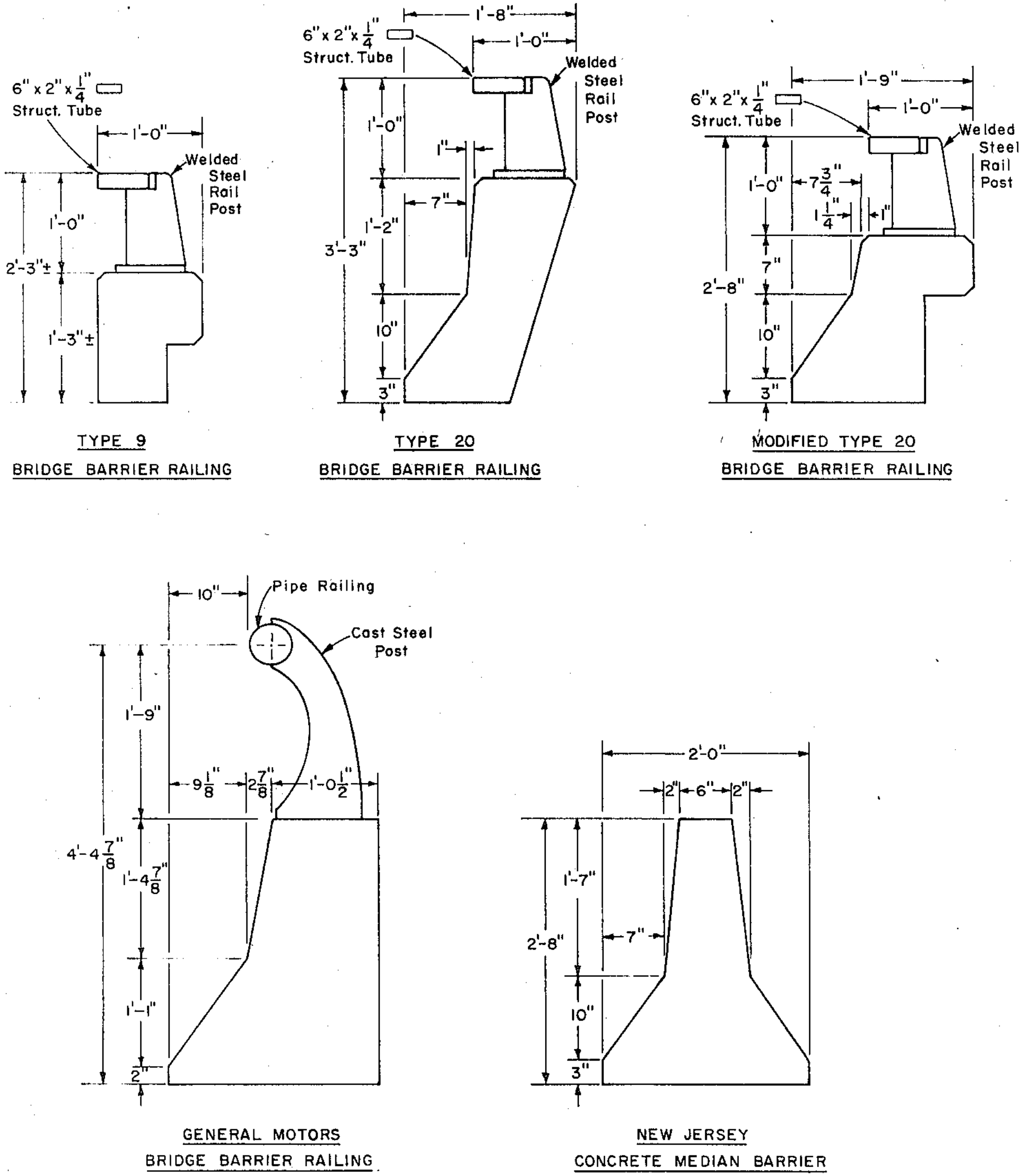


Figure 2

DETAILS OF HIGHWAY BARRIERS WITH CONCRETE PARAPETS

II. CONCLUSIONS AND IMPLEMENTATION

A. Conclusions

The following conclusions are based on an analysis of the results of the full scale vehicle impact tests reported herein:

1. The Modified Type 20 Bridge Barrier Rail with an overall height of 32" will retain and redirect heavy passenger vehicles impacting at velocities and approach angles of up to 65 mph/15 degrees. However, vehicular damage will be more severe than that sustained when striking the 39" high California Type 20 Bridge Barrier Rail.

2. The reinforced lightweight concrete design as used in the test barrier did not withstand the loading of a vehicle impacting the barrier at a velocity and approach angle of 72 mph/25 degrees.

3. If a steel rail is to be used with the safety shaped concrete parapet, a parapet height near 27-inches and an over-all barrier height near 39-inches should be maintained as specified for the standard California Type 20 Bridge Rail. This height would preclude overriding of the barrier by passenger cars impacting at a high speed and wide angle, and would minimize vehicular damage at the more prevalant flat angles of impact.

4. Results from the limited instrumentation data indicated that passengers in vehicles impacting the Modified Type 20 Barrier at angles less than 25 degrees would not receive injuries any more severe than those in vehicles impacting the standard Type 20 Bridge Rail.

B. Implementation

1. As a result of tests reported herein, the Modified Type 20 Bridge Barrier Rail is not recommended for use. Although the modified design is superior to vertically faced barriers with regards to vehicle damage, it is not as effective as the standard Type 20 design.

2. After reviewing all crash tests on the modified and standard California Type 20 Bridge Rail designs, the Bridge Department has adopted an all concrete bridge

rail termed "Concrete Barrier - Type 25". This barrier has an over-all height of 32 inches and a traffic side profile identical to the California Type 50 Concrete Median Barrier. No crash tests were deemed necessary to justify use of the Type 25 Bridge Barrier Rail which will appear in the new California Standard Plans to be published in 1973. The Type 20 Bridge Barrier Rails will not be included in the 1973 Standard Plans.

III. TECHNICAL DISCUSSION

A. Test Conditions

1. Barrier Design

The Modified Type 20 Bridge Barrier Rail design was developed by the California Division of Highways Bridge Department and submitted to the Materials and Research Department for testing. The test installation, consisting of 65-ft. of Modified Type 20 Bridge Rail, was constructed at the Materials and Research Department test facility at the Lincoln, California, Airport (Figure 3).

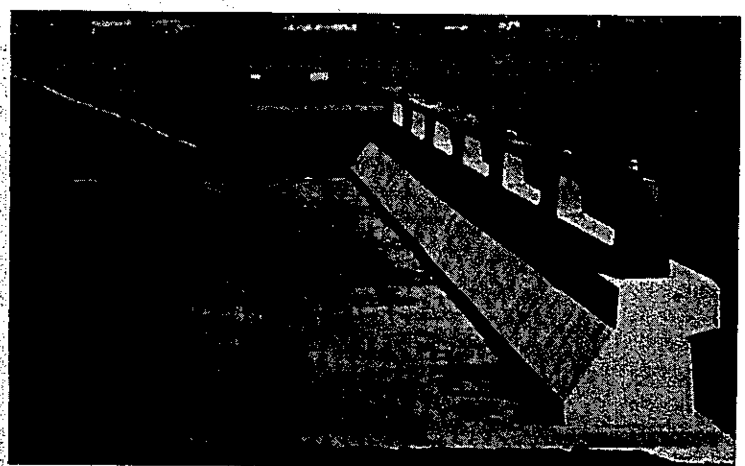


FIGURE 3 - MODIFIED TYPE 20 BRIDGE RAIL AT TEST FACILITY

The Modified Type 20 design consists of a steel post and railing system mounted on top of a reinforced lightweight concrete parapet. The steel post and rail system was developed in a previous test series of the California Type 9 Bridge Barrier Rail[4]. This system consists of steel posts fabricated of structural steel conforming to the requirements of ASTM Designation A36 and steel railing fabricated from 6- by 2-inch by 12.02 lb. structural steel tubing conforming to the requirements of ASTM Designation A500, Grade B. The 3/4-inch welded stud rail-to-post connector and the interior sleeve rail splice, proven effective in previous test series [1,4] were employed. The fabricated steel posts were spaced at 10-ft. centers and were secured to the concrete parapet with one 3/4-inch diameter by 8-inch long bolt and one 1-inch diameter by 12-inch long bolt cast in the concrete. These high strength bolts conformed to the requirements of ASTM Designation A325.

The concrete portion of the barrier consisted of a 20-inch high by 65-ft. long reinforced lightweight concrete parapet constructed on a reinforced lightweight concrete cantilevered deck. The safety shape contour of the traffic-side face of the parapet was patterned after the successfully tested New Jersey Median Barrier [2]. The lightweight concrete was a 7-sack mix conforming to the requirements of Sections 51, 89, and 90 of the 1971 California Standard Specifications. The minimum 28-day compressive strength was 4540 lbs.

The total barrier height was 32 inches from the bridge deck to the top of the steel rail member. The deck and parapet reinforcing, as well as other details of the Modified Type 20 Bridge Barrier Rail, are shown on Figure 4. This system was designed in accordance with the requirements of the "Standard Specifications for Highway Bridges" adopted by the American Association of State Highway Officials in 1969.

2. Test Parameters

The test guidelines established by the Highway Research Board Committee on Guardrails and Guideposts[5] specify the use of a 4000± lb. vehicle, an impact velocity of 60 mph, and an impact angle of 25 degrees. For the tests reported herein, the vehicle weighed 4895 lb. and maximum impact velocity was 72 mph. Although these values exceed the HRB guidelines, they are more representative of the vehicle weights and speeds currently present on California freeways. The impact velocities and approach angles selected for these tests ranged from 45 to 72 mph and from 5 to 25 degrees. The lower velocities and angles were chosen in recognition of a recent study reported in Highway Research Board Special Report 107 which indicates that approximately 75% of the vehicles departing from the traveled way do so at an angle of 15 degrees or less and almost 60% depart at 10 degrees or less. Thus, it was felt important to determine the redirective capability of this barrier with regard to vehicle trajectory and damage at the lower impact speeds and angles. This was particularly relevant

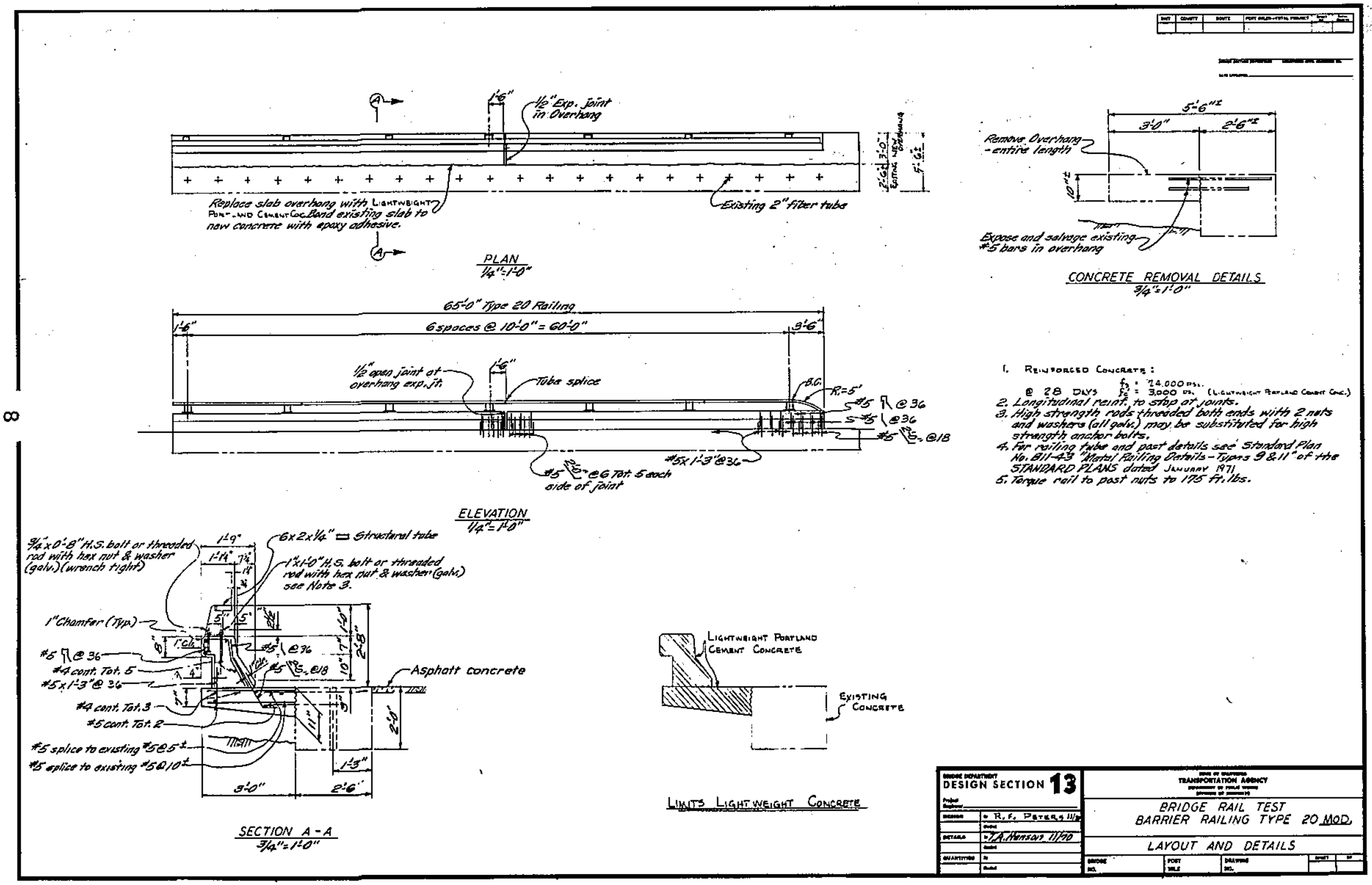


FIGURE 4

DETAILS OF MODIFIED TYPE 20 BRIDGE BARRIER RAIL
(Reduced plan - not to scale)

with this barrier design because of its "safety shape" parapet contour, which was proven effective in previous test series [1,2] in reducing vehicle damage at the lower angle impacts.

Due to the lowered height of the concrete "safety shape" parapet, the tendency of a vehicle to climb this barrier was unknown. It was felt that various combinations of speed and angle should be tried; however, it became apparent from the initial 5° angle tests, that the restraining action of the steel rail on the vehicle body tended to restrict vehicle rise as the impact speeds increased. Therefore, only the high velocity test was performed for the larger angles of impact.

The impact velocity and approach angle for each of the 7 tests are tabulated in Table 1.

TABLE 1 - SUMMARY OF IMPACT VELOCITIES AND APPROACH ANGLES

Test No.	Velocity (mph)	Angle of Impact
281	47	5°
282	54	5°
283	57	5°
284	62	5°
285	57	10°
286	65	15°
287	72	25°

3. Test Equipment and Procedure

The test vehicles used in this study were 1969 Dodge sedans. Their test weight, including on-board instrumentation, was 4895 lbs. These vehicles were retired California Highway patrol sedans modified for test purposes. Control of the vehicle during the impact approach was accomplished by remote radio control from a command car following approximately 100-feet behind the test vehicle.

Still cameras along with high speed and normal speed movie cameras were used to record the before and after impact events.

To obtain information relative to the kinematics and deceleration forces a human would be subjected to during these impacts, an anthropometric dummy occupied the driver's seat of the crash vehicle for all of the tests reported herein. The dummy (Model P/N 292-850), manufactured by Sierra Engineering Company, is a 50th percentile male weighing 165 lbs. It was restrained during the tests by a standard lap belt.

Accelerometers were mounted on the vehicle and dummy to obtain deceleration data for use in judging the severity of injuries to passengers. A mechanical Impactograph mounted on the floorboard behind the front seat served as a backup for the accelerometers.

The Appendix contains a detailed description of:

a. The test vehicle mechanical instrumentation.

b. Photographic equipment and data collection techniques.

c. Electronic instrumentation and data reducing methods.

d. Accelerometer and seat belt transducer records.

e. Impactograph records.

B. Test Results

1. Introduction

The following pages contain descriptions of the seven full scale impact tests conducted in this study. These descriptions are based on analysis of the high-speed data film, interpretation of deceleration instrumentation recordings, physical evidence examined at the test site, and laboratory evaluation of barrier components.

2. Tests 281 - 284

The first four tests of the series (Tests 281 - 284) were conducted at an approach angle of 5 degrees. The impact velocity was progressively increased for each test; 47 mph/Test 281; 54 mph/Test 282; 57 mph/Test 283; 62 mph/Test 284. The purpose of increasing the impact velocity was to obtain correlation data between (1) vehicular response, (2) vehicular damage and (3) occupant response vs. impact velocity at a constant approach angle.

The vehicle in each of the four tests was effectively retained and redirected without any significant damage to the bridge rail (Figure 5).

Vehicular damage, which was considered minor, increased only slightly relative to the increase in impact velocity (Figure 6). The same test vehicle was reused for all four 5° tests with only cosmetic sheet metal and paint repairs required between tests and for a subsequent larger angle test.

The vehicular/barrier interactions were also very similar for each test, and the following test descriptions are applicable to each of the four tests with the noted exceptions.

Over-all vehicular dynamics throughout the impact event were good with no tendency for the vehicle to jump and only a 3 degree body roll away from the barrier. Vehicular redirection was accomplished smoothly and parallel with the barrier to an exit angle of less than 2 degrees. The initial vehicle/barrier contact was made by the left front wheel at the lower face of the concrete parapet. Tire scrub marks on the face of the parapet delineated a contact length of approximately 25 ft. and a maximum wheel climb on the parapet face of 1.5 ft. (left front wheel). The maximum rise of the vehicle body was 0.6 ft.

Vehicle sheet metal contact with the barrier was at the left front fender where the steel railing creased the sheet metal to a depth of 0.2 ft. There was also minor sheet metal deformation and paint abrasion along the left side and at the left rear fender. There was no apparent damage to the vehicle suspension or steering system from the four impacts.

Many of the details and results of the four 5° tests (281 thru 284) are summarized in Figures 7 through 10.

The lap belt restrained dummy driver sustained no visible damages nor was there any physical evidence within the vehicular passenger compartment to indicate that the dummy had been subjected to high deceleration rates. This was verified by the deceleration instrumentation recordings which are summarized in Table 2 along with those obtained from the mechanical Impactograph. The values obtained with the Impactograph should not be construed as "G" forces. However, comparison of the values recorded in each test is an indication of the relative impact severity.

A more complete analysis of the deceleration data for these four tests, including the somewhat inconsistent dummy decleration values for Test 283, is contained in the Discussion, Section III-C-2. A description of the instrumentation and selected data records are included in the Appendix. Transducer locations are graphically illustrated on Figure 2A, Appendix.

TABLE 2

SUMMARY OF INSTRUMENTATION DATA FROM TESTS 281-284

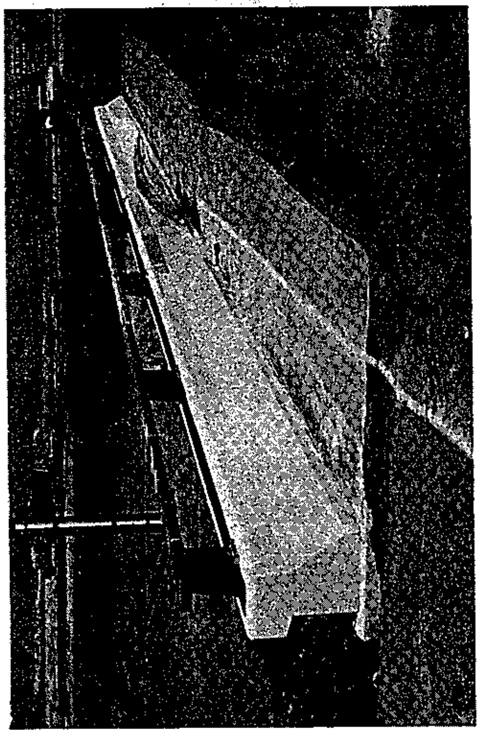
ACCELEROMETER RESULTS

Accelerometer Location/Orientation	Highest 50 ms Average Value of Deceleration in G's	Time After Impact In Seconds	Test No.
1. Dummy Head (Vectorial resultant of data from long., lat., and vert. accelerometers)	6.1	.350-.400	281
	5.2	.503-.553	282
	17.2	.363-.413	283
	9.5	.335-.385	284
2. Dummy Chest (longitudinal motion)	1.7	.365-.415	281
	1.3	.525-.575	282
	2.6	.400-.450	283
	1.7	.320-.370	284
3. Vehicle - long. motion (Location B, Figure 2A)	1.4	.205-.255	281
	0.3	.293-.343	282
	1.5	.203-.253	283
	1.6	.203-.253	284
4. Vehicle - lateral Motion (Location B, Figure 2A)	1.7	.240-.290	281
	1.2	.273-.323	282
	2.6	.223-.273	283
	3.5	.225-.275	284

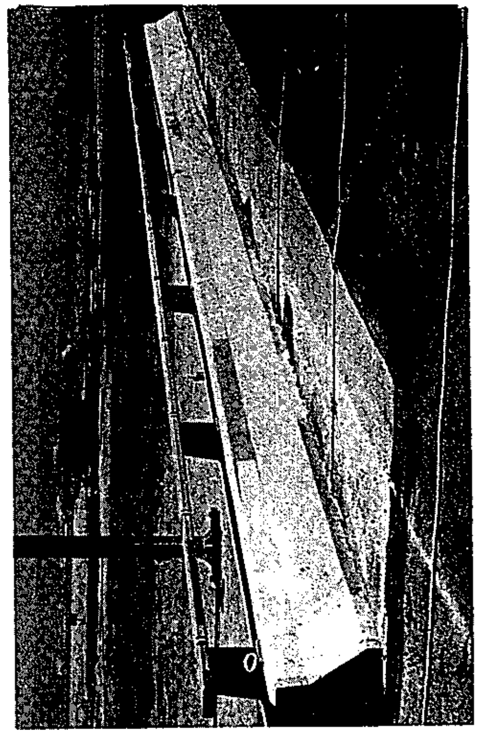
TABLE 2 (Continued)

VEHICLE IMPACTOGRAPH AND OTHER INSTRUMENTATION RESULTS

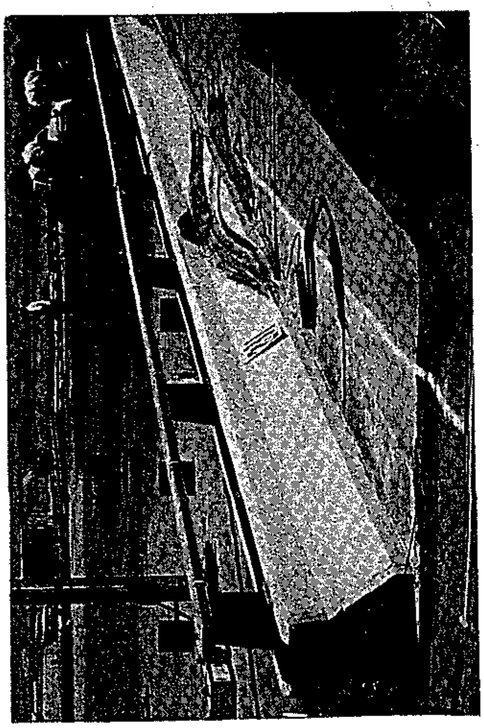
Impactograph Recordings (Peak Readings) Direction	Test Numbers 281	282	283	284
Vertical - (down units)	5	5	5	6
Longitudinal (forward units)	3	2	7	4
Lateral (left units)	6	6	7	7
Gadd Severity Index	18	10	175	73
Max. Seat Belt Transducer Load (lbs.)	130	0	240	150



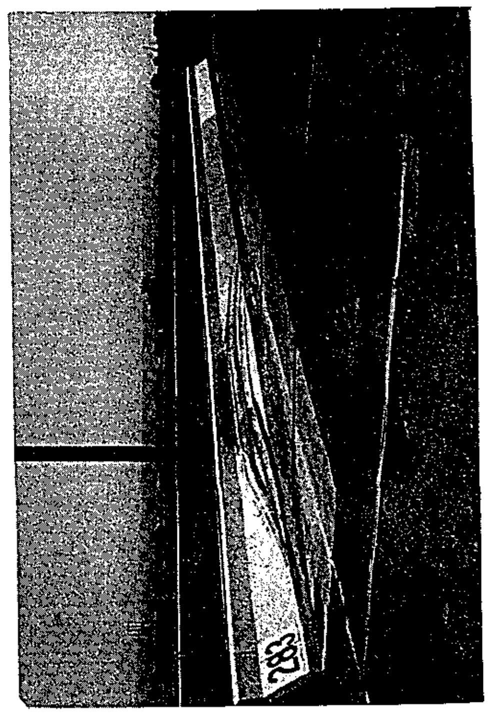
TEST 282
54 mph 5°



TEST 284
62 mph 5°



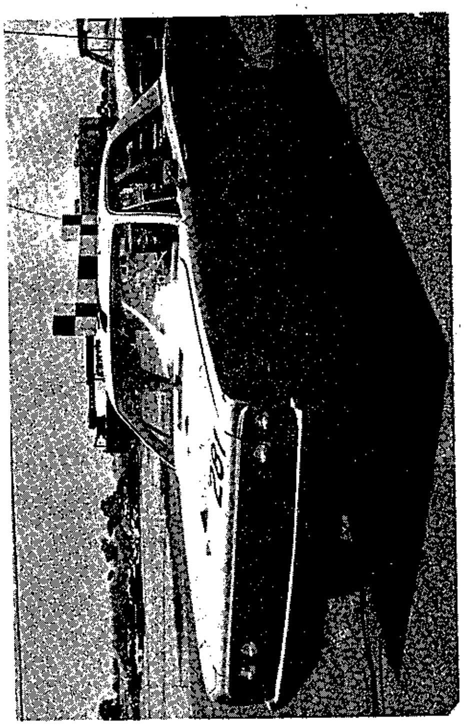
TEST 281
47 mph 5°



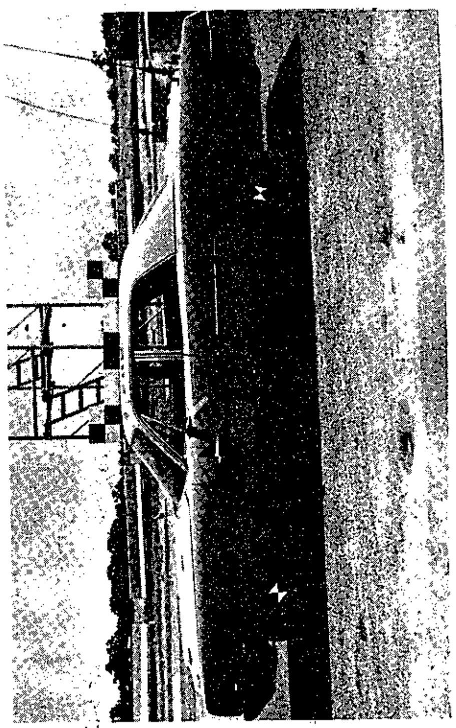
TEST 283
57 mph 5°

FIGURE 5

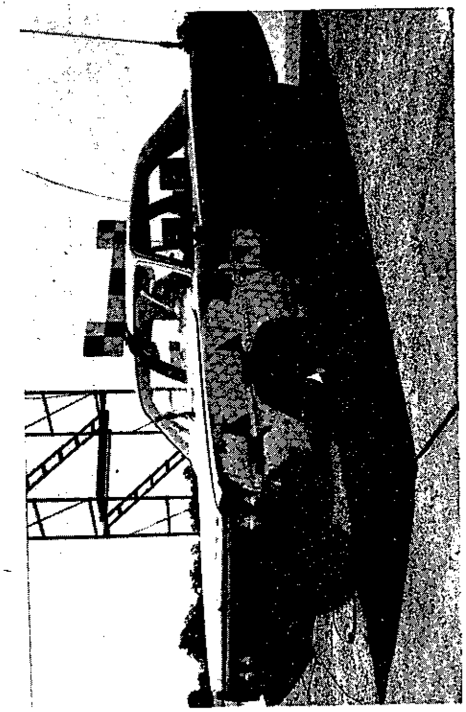
COMPARISON OF BARRIER DAMAGE FOR TESTS 281-284



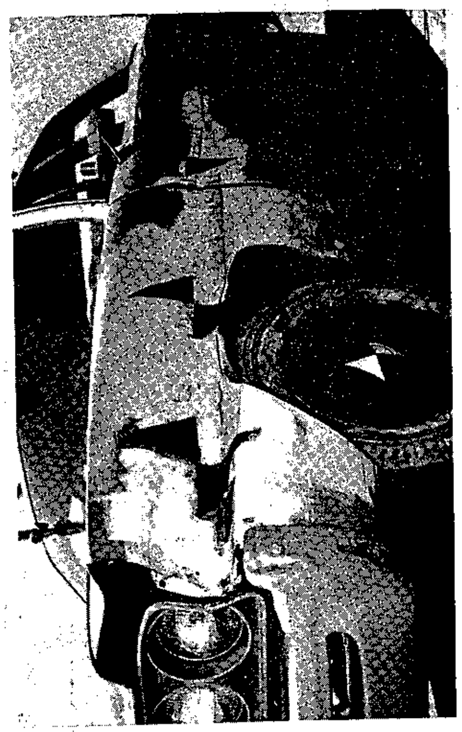
TEST 281
47 mph 5°



TEST 282
54 mph 5°
(TEST 281 VEHICLE REUSED W/O REPAIR)



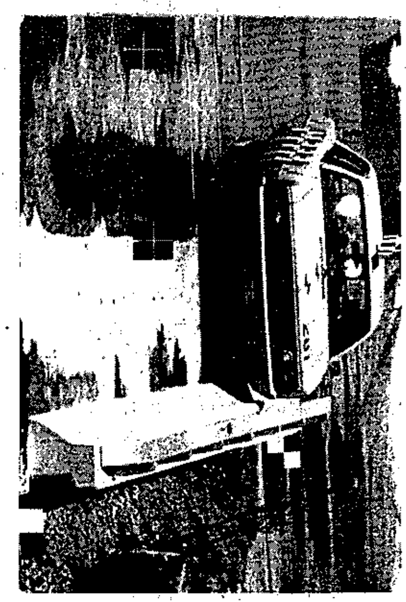
TEST 283
57 mph 5°
(TEST 282 VEHICLE REUSED AFTER
COSMETIC FENDER REPAIR



TEST 284
62 mph 5°
(TEST 283 VEHICLE REUSED W/O REPAIR)

FIGURE 6

COMPARISON OF VEHICULAR DAMAGE FOR TESTS 281-284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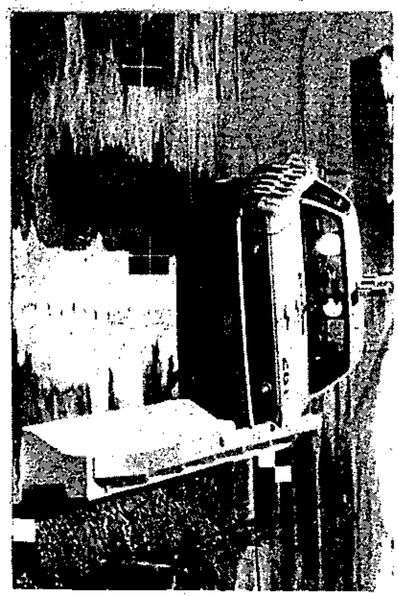
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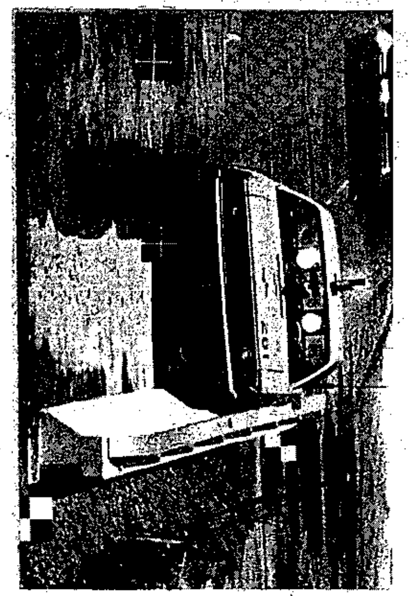
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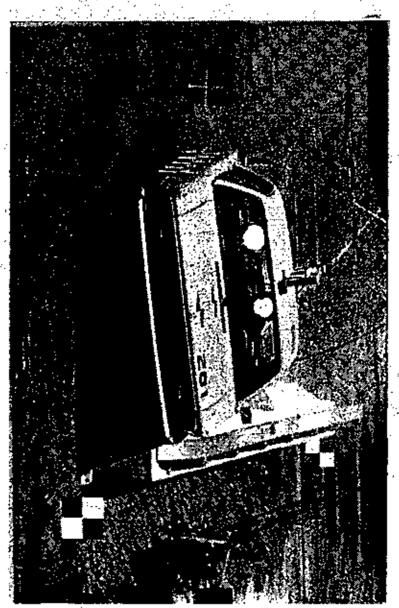
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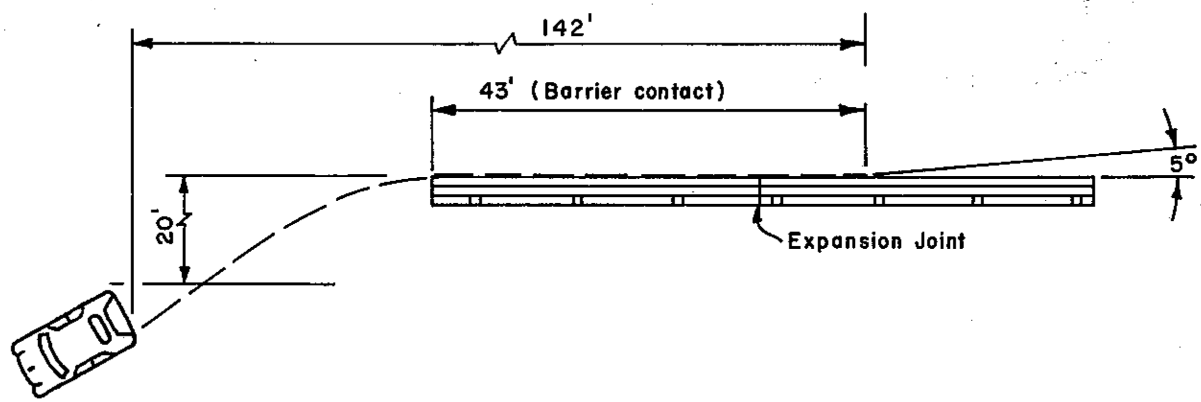
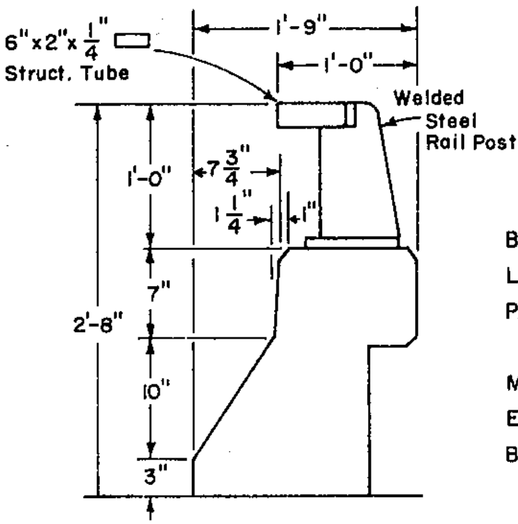
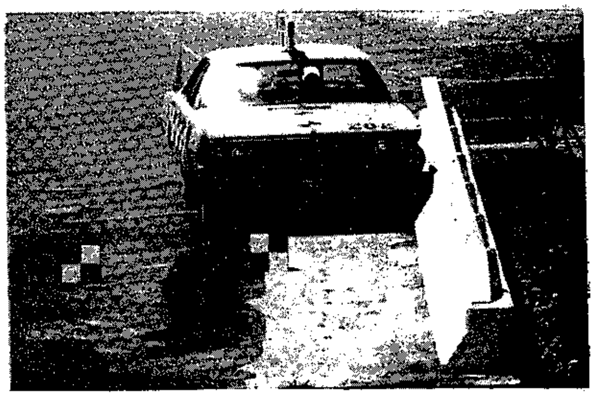




BARRIER TESTED		Modified Type 20 Bridge Rail
LENGTH OF INSTALLATION		65'±
PASSENGER COMPARTMENT DECEL. (Highest 50ms average)	Long.	1.4
	Lat.	1.7
MAXIMUM VEHICLE RISE		0.5'
EXIT ANGLE		0°
BARRIER DAMAGE		Negligible

TEST NO.	281
DATE	7/14/71
VEHICLE	1969 Dodge Sedan
SPEED	47 mph
IMPACT ANGLE	5°
VEHICLE WEIGHT (Incl./dummys & instrumentation	4895 Lbs
DUMMY RESTRAINT	Lap Belt



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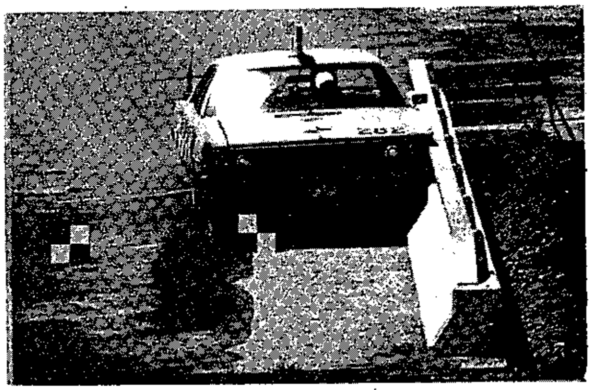

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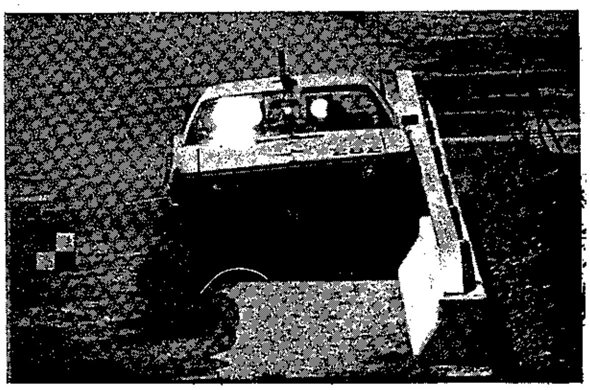

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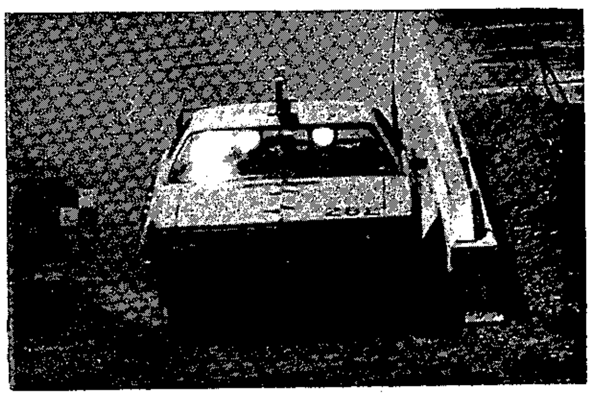

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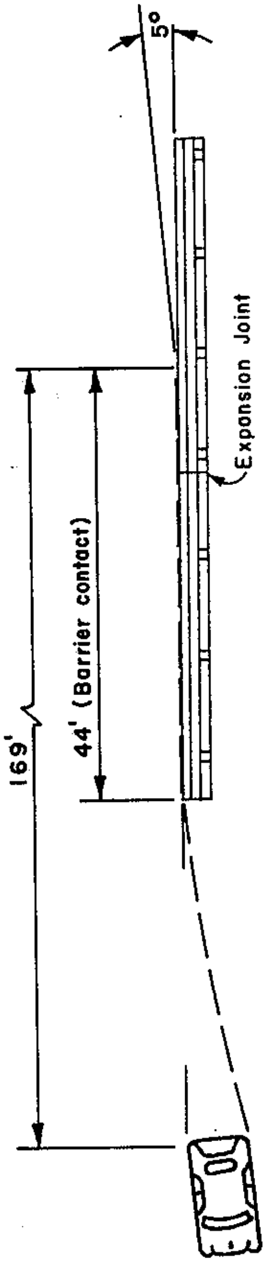
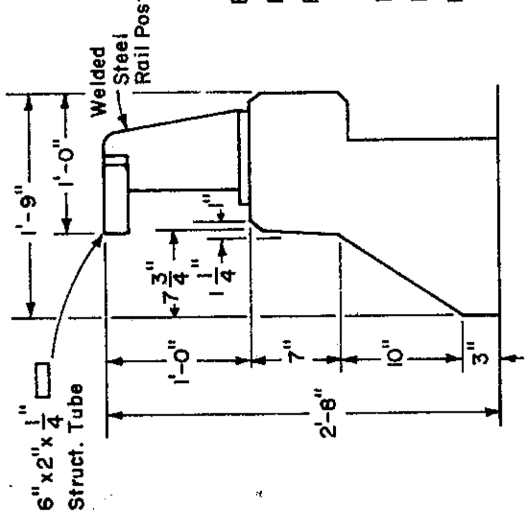


TEST NO.	282
DATE	7/14/71
VEHICLE	1969 Dodge Sedan
SPEED	54 mph
IMPACT ANGLE	5°
VEHICLE WEIGHT (Incl./dummys & instrumentation)	4895 Lbs
DUMMY RESTRAINT	Lap Belt

BARRIER TESTED		Modified Type 20 Bridge Rail
LENGTH OF INSTALLATION		65' ±
PASSENGER COMPARTMENT DECEL. (Highest 50ms average)	Long.	0.3
	Lat.	1.2
MAXIMUM VEHICLE RISE		0.5'
EXIT ANGLE		0°
BARRIER DAMAGE		Negligible

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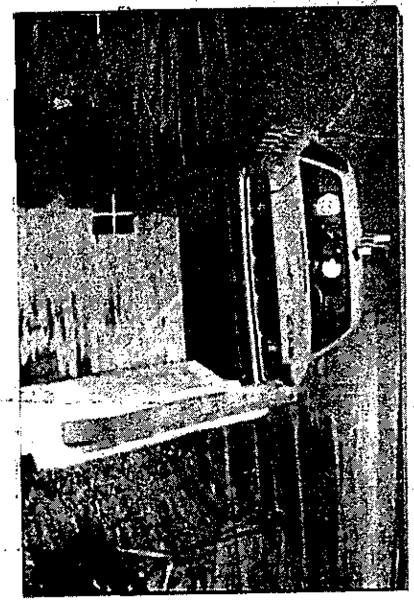
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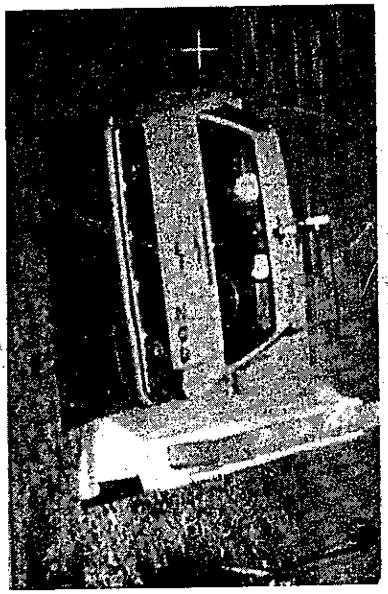
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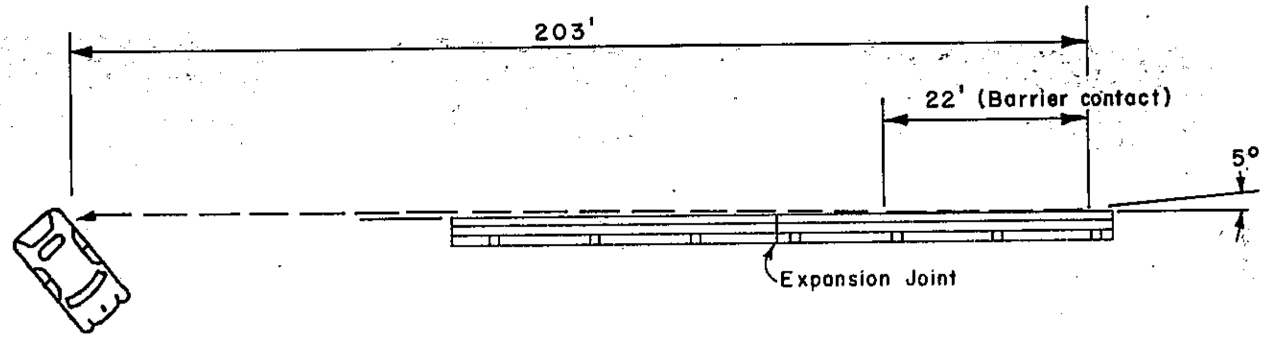
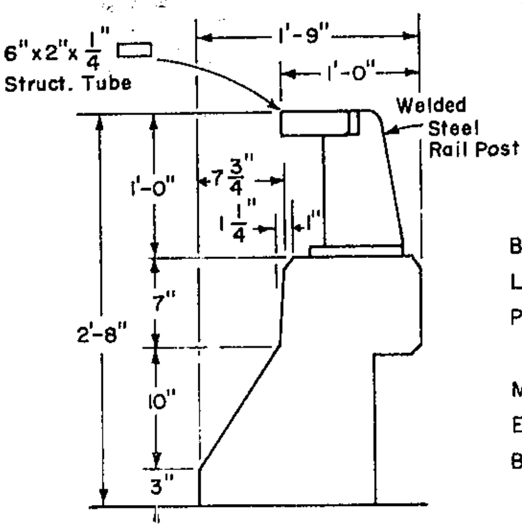
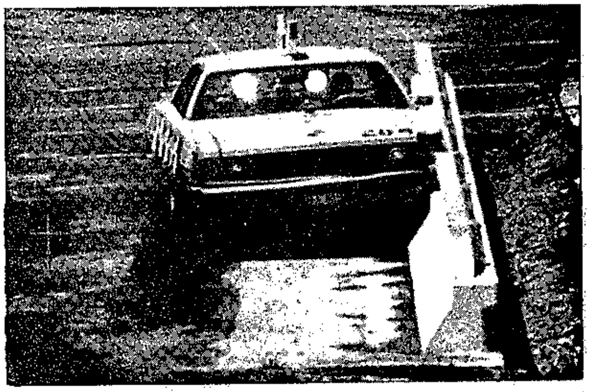




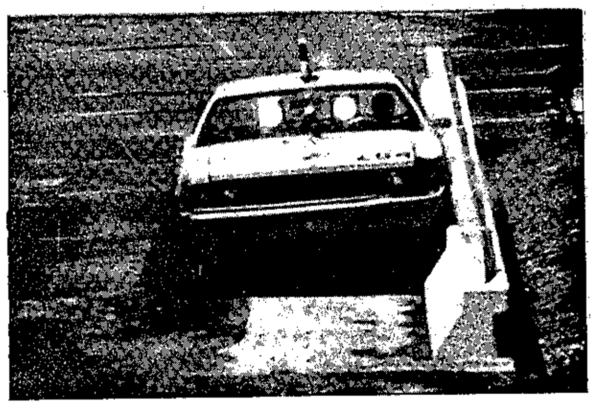
BARRIER TESTED	Modified Type 20 Bridge Rail
LENGTH OF INSTALLATION	65' ±
PASSENGER COMPARTMENT DECEL. (Highest 50ms average) Long.	1.5
Lat.	2.6
MAXIMUM VEHICLE RISE	0.6'
EXIT ANGLE	1°
BARRIER DAMAGE	Negligible

TEST NO.	283
DATE	7/21/71
VEHICLE	1969 Dodge Sedan
SPEED	57 mph
IMPACT ANGLE	5°
VEHICLE WEIGHT (Incl./dummys & instrumentation	4895 Lbs
DUMMY RESTRAINT	Lap Belt

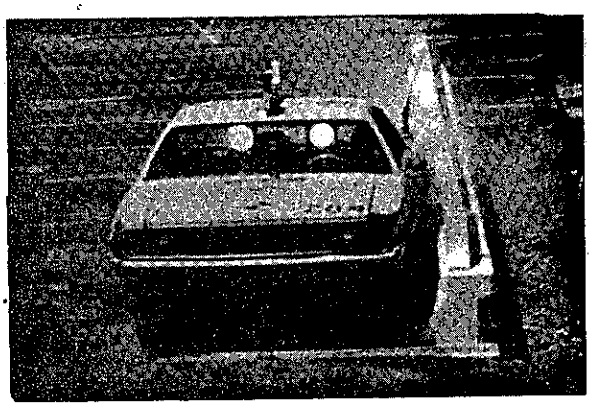
Impact



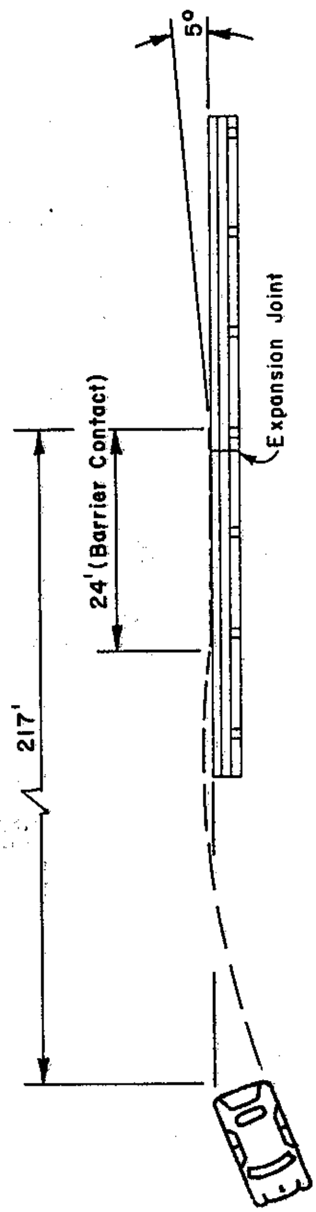
I +0.10 Sec.

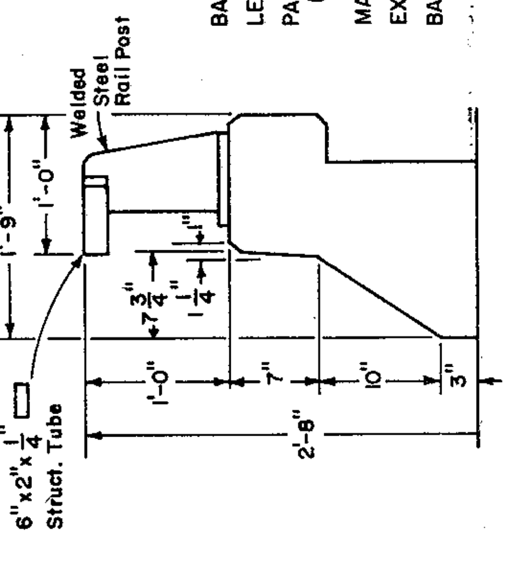


I + 0.20 Sec.



I + 0.40 Sec.





TEST NO.	284
DATE	7/21/71
VEHICLE	1969 Dodge Sedan
SPEED	62 mph
IMPACT ANGLE	5°
VEHICLE WEIGHT (Incl./dummys & instrumentation)	4895 Lbs
DUMMY RESTRAINT	Lap Belt
BARRIER TESTED	Modified Type 20 Bridge Rail
LENGTH OF INSTALLATION	65' ±
PASSENGER COMPARTMENT DECEL. (Highest 50ms average)	Long. 1.6 / Lat. 3.5
MAXIMUM VEHICLE RISE	0.6'
EXIT ANGLE	1°
BARRIER DAMAGE	Negligible

3. <u>Test 285</u>

Test No. 285 was conducted at an impact velocity and angle of 57 mph/10 degrees. These test parameters were selected to determine what effect increasing the approach angle would have on vehicular response and damage in comparison with the four 5 degree tests (Tests 281 - 284). The bridge rail effectively retained and redirected the vehicle without sustaining any damage (Figure 11). Vehicle damage was slightly more severe than that experienced in the first four tests (Figure 12).

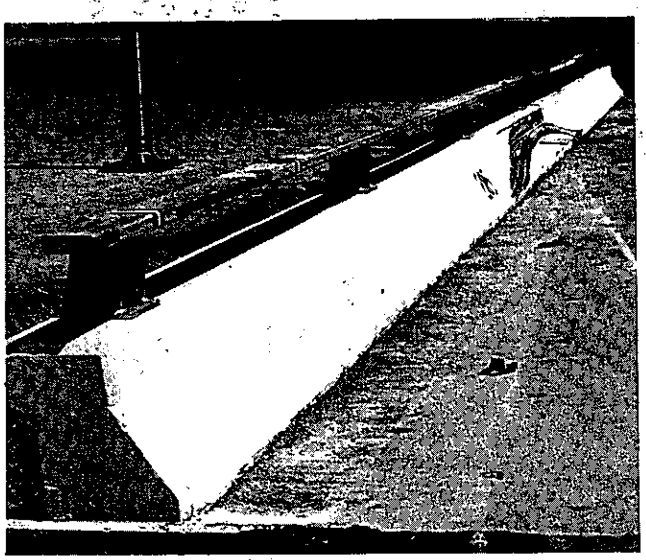


FIGURE 11 - BARRIER DAMAGE
TEST 285

FIGURE 12 - VEHICLE DAMAGE
TEST 285

Vehicle dynamics throughout the impact event were good; there was no tendency for the vehicle to jump. There was a 4 degree body roll away from the barrier. The vehicle was smoothly redirected nearly parallel with the barrier to an exit angle of approximately 2 degrees. The initial vehicle/barrier contact, made virtually simultaneously by the left front tire and fender, occurred at railing post No. 3. Tire scrub marks on the face of the parapet delineated a contact length of approximately 21 ft. and a maximum wheel climb on the parapet face of 1.6 ft. (left front wheel). The maximum rise of the vehicle body was 0.7 ft.

Vehicle sheet metal contact with the barrier was at the left front fender where the steel railing creased the sheet metal to a depth of 0.45 ft. The left end of the front bumper and the left frame horn were also deformed. There was minor sheet metal deformation and paint scrapes along the entire left side of the vehicle to the rear fender which was creased to a depth of 0.14 ft. The rear fender deformation was indicative of a more severe rear-end slap than had occurred in any of the first four 5° tests. There was no apparent damage to the suspension or steering systems and the vehicle was still operable.

The lap belt restrained dummy driver sustained no visible damage nor was there any physical evidence within the vehicular passenger compartment to indicate that the dummy had been subjected to high deceleration rates. Due to an erroneous erasing of the electronic data during its processing, the only record of decelerations involved in this impact is from the mechanical Impactograph. The values obtained with the Impactograph are shown in Table 3 and should not be construed as "G" forces. However, a comparison with those values recorded in the other tests of this series will give an indication of the relative impact severity.

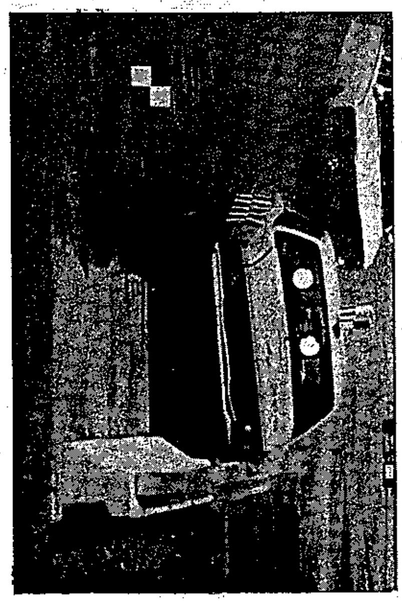
TABLE 3

VEHICLE IMPACTOGRAPH RESULTS (Peak Values) TEST 285

Vertical (down units)	4
Longitudinal (forward units)	4
Lateral (left units)	9

Figure 13 summarizes many of the details and results of Test 285.

Impact + 0.03 Sec.



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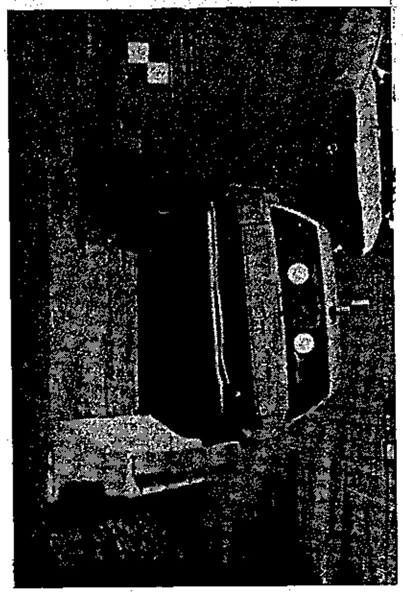

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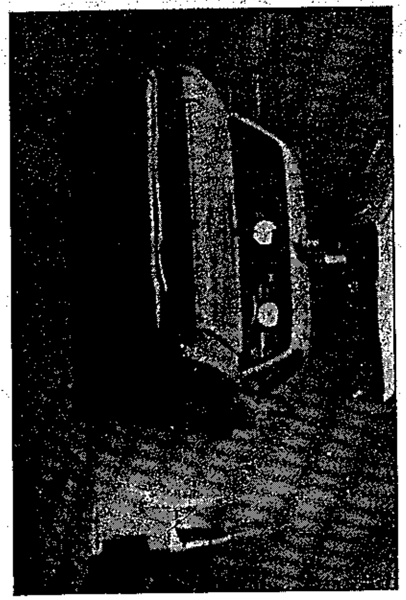

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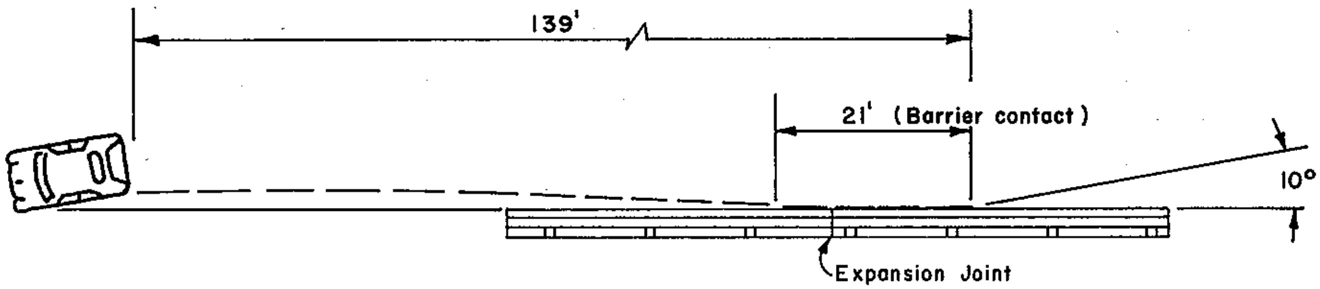
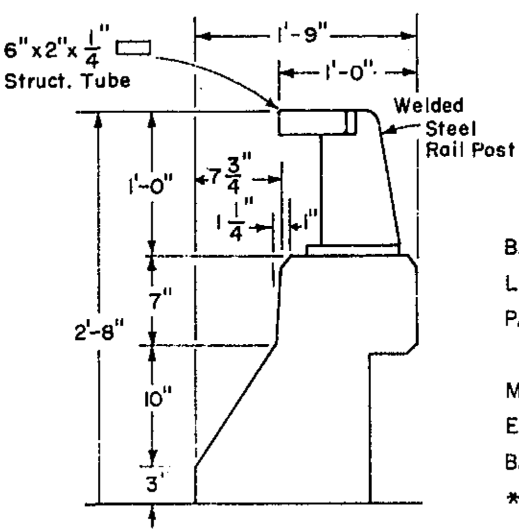




BARRIER TESTED	Modified Type 20 Bridge Rail
LENGTH OF INSTALLATION	65' ±
PASSENGER COMPARTMENT DECEL. (Highest 50ms average) Long.	*
Lat.	*
MAXIMUM VEHICLE RISE	0.7'
EXIT ANGLE	2°
BARRIER DAMAGE	Negligible

* ERRONEOUS DATA

TEST NO.	285
DATE	8 /4 /71
VEHICLE	1969 Dodge Sedan
SPEED	57 mph
IMPACT ANGLE	10°
VEHICLE WEIGHT (Incl./dummys & instrumentation	4895 Lbs
DUMMY RESTRAINT	Lap Belt

4. Test 286

Test No. 286 was conducted at an impact velocity and angle of 65 mph/15 degrees. These test parameters were selected not only to correlate with the first 5 tests of this series but also to obtain a comparison with the results of Test No. 233, a 64 mph 15° test, conducted on the standard California Type 20 design[1].

The bridge rail effectively retained and redirected the vehicle without sustaining any damage (Figure 14). Vehicle damage was relatively severe (Figure 15).

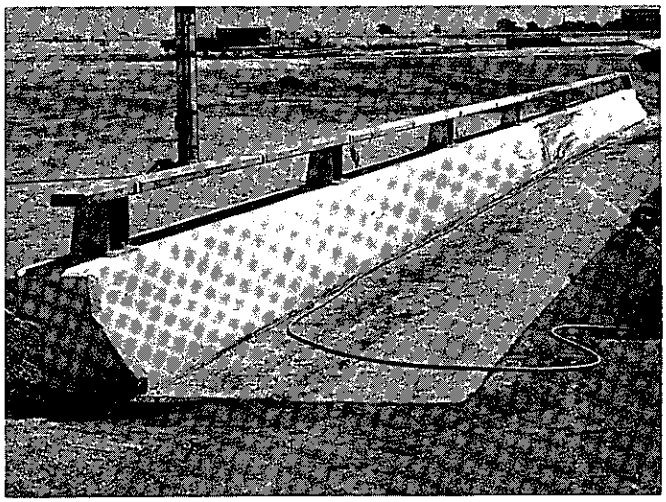


FIGURE 14 - BARRIER DAMAGE
TEST 286

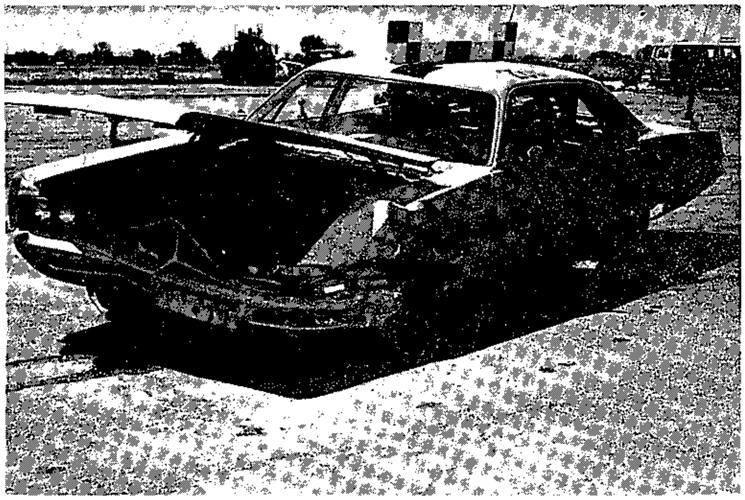


FIGURE 15 - VEHICLE DAMAGE
TEST 286

Vehicle dynamics throughout the impact event, although satisfactory, were more severe than those observed in the preceding five tests. Although vehicular redirection was accomplished relatively smoothly, the vehicle rebounded off the barrier, to a maximum rebound of 8.5 ft. However, the vehicle body roll away from the barrier was only 4 degrees and the exit angle 2 degrees with the barrier, the same as in Test 285.

The initial vehicle/barrier contact, made virtually simultaneously by the left front tire and fender, occurred at post No. 4. Tire scrub marks on the face of the parapet delineated a contact length of approximately 15 ft. and a maximum wheel climb on the parapet face of 1.6 ft. (left front wheel). The maximum rise of the vehicle body was 1.2 ft.

Initial vehicle sheet metal contact with the barrier was at the left front fender where the steel railing severely deformed the sheet metal at headlight level. The fender sheet metal and the front bumper were crushed back against the left front tire. The tire was flattened and the wheel rim bent. The left front frame members were bent and the radiator was pushed back against the engine block. There was slight sheet metal deformation and paint abrasions along the left side to the rear fender which was also slightly creased.

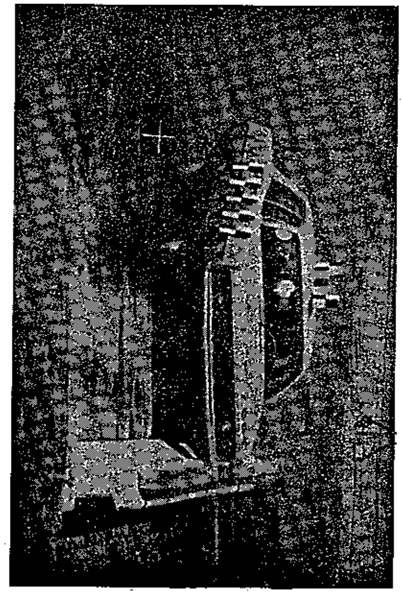
The lap belt restrained dummy sustained no visible damage nor was there any evidence within the vehicle passenger compartment that the dummy had been subjected to high deceleration rates. The electronic instrumentation data were lost in this test also. Therefore, the only record of the deceleration forces involved in this impact is from the mechanical Impactograph. The values obtained with the Impactograph are shown in Table 4 and should not be construed as "G" forces. However, a comparison with those values obtained in other tests will give an indication of the relative impact severity.

TABLE 4

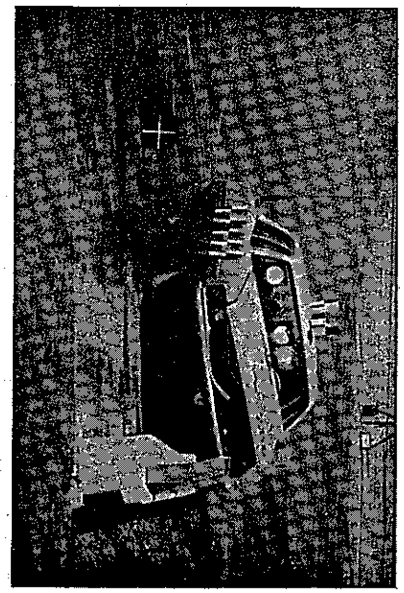
VEHICLE IMPACTOGRAPH RESULTS (Peak Values) - TEST 286

Vertical (down units)	8
Longitudinal (forward units)	6
Lateral (left units)	11

Figure 16 summarizes many of the details and results of Test No. 286.



Impact



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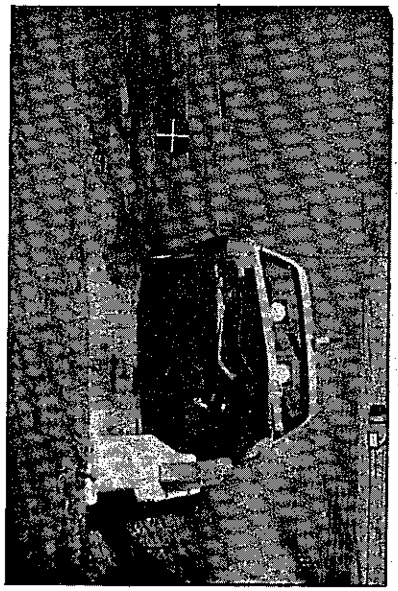
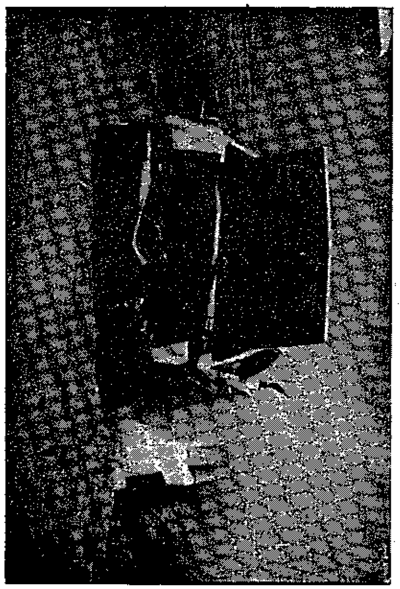


I + 0.20 Sec.



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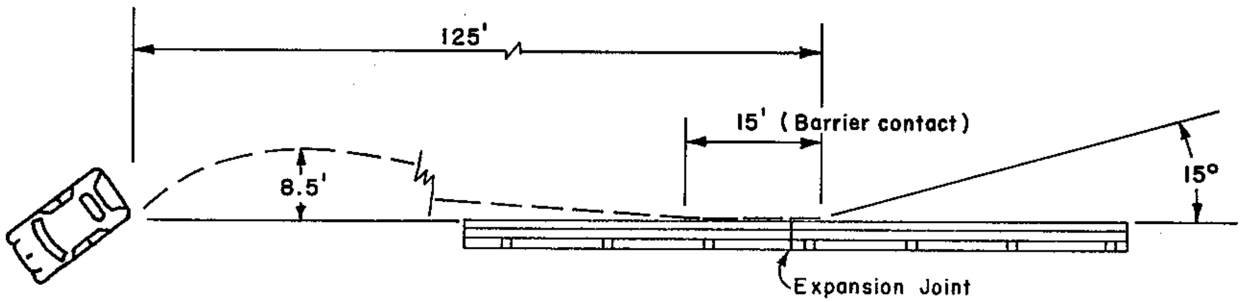
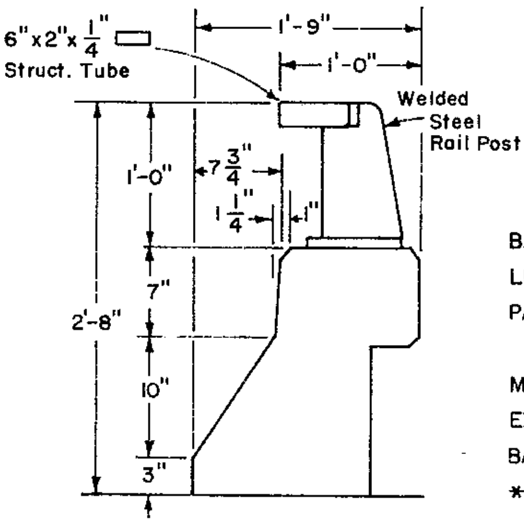




BARRIER TESTED	Modified Type 20 Bridge Rail
LENGTH OF INSTALLATION	65' ±
PASSENGER COMPARTMENT DECEL. (Highest 50ms average) Long.	*
Lat.	*
MAXIMUM VEHICLE RISE	1.2'
EXIT ANGLE	2°
BARRIER DAMAGE	Negligible

* ERRONEOUS DATA

TEST NO.	286
DATE	8/12/71
VEHICLE	1969 Dodge Sedan
SPEED	65 mph
IMPACT ANGLE	15°
VEHICLE WEIGHT (Incl./dummys & instrumentation	4895 Lbs
DUMMY RESTRAINT	Lap Belt

5. Test 287

The final test of this series (Test 287) was conducted at an impact velocity and angle of 72 mph/25 degrees. The purpose of this test was (1) to determine the vehicular response and damage from a high-speed wide angle impact and (2) to investigate the structural capabilities of the reinforced, lightweight concrete parapet when subjected to severe impact loading. Test results were compared with those obtained from the preceding six tests of this series and with those obtained from Test No. 235, a 66 mph, 25° test, conducted on the standard Type 20 design [1].

The bridge rail did not retain the vehicle in this test. The barrier was heavily damaged and the vehicle was totally destroyed (Figures 17 and 18).

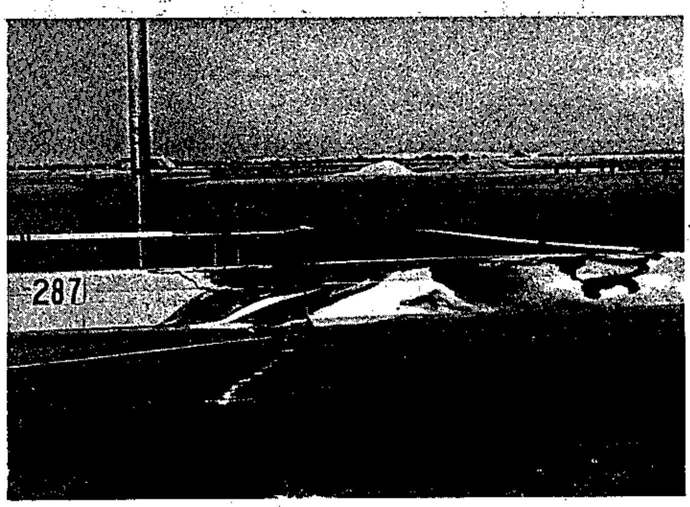


FIGURE 17 - BARRIER DAMAGE
TEST 287

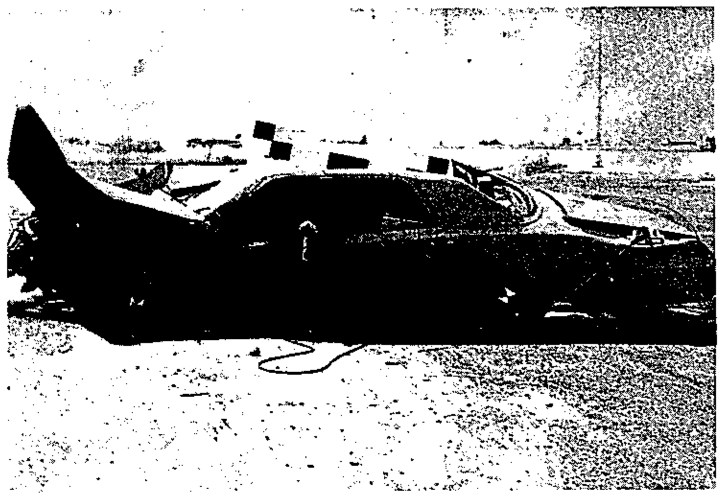


FIGURE 18 - VEHICLE DAMAGE
TEST 287

The initial vehicle/barrier contact occurred simultaneously with the left front tire and fender 1.5 ft. upstream of post No. 4. Tire scrub marks on the face of the parapet delineated the path of the wheel from post No. 4 downstream for a distance of 6-ft., up the face and over the top of the parapet. The vehicle body rode up onto the parapet, displacing the steel railing as the vehicle was redirected parallel with the barrier. Straddling the parapet, the vehicle continued for the length of the barrier, tilted longitudinally to the right as it came off the end of the parapet, landed on its right front end, tilted to the left and rolled. It continued in a series of three rollovers, coming to rest upright approximately 185 ft. downstream of impact.

The vehicle was totally destroyed with both sides, top, front, and rear heavily damaged. The barrier was likewise extensively damaged. Post Nos. 5 and 6 were deformed with post No. 5 displaced 100 ft. downstream and 45 ft. behind the barrier. Three rail sections were bent with the rail stud bolts broken off two of these sections. The terminal rail section was displaced 65 ft. downstream and 60 ft. behind the barrier. There was considerable concrete spalling of the upper parapet at post Nos. 4, 5, and 6. The post anchor bolts at post No. 4 were pulled free of the parapet. At post No. 5 the anchor bolts were pulled out of the parapet and displaced downstream with the post. Post Nos. 6 and 7 were still secured to the parapet. Many of the details and results of Test 287 are summarized in Figure 19.

The lap belt restrained dummy driver did not sustain any visible damage that would represent fatal injuries. However, within the vehicle passenger compartment the left front door was severely deformed from lateral impact by the dummy. Deceleration instrumentation recordings verified that severe forces were involved in this impact. These values are summarized in Table 5 along with those obtained from the mechanical Impactograph.

A complete analysis of all the deceleration data is contained in the Discussion, Section III-C. A description of the instrumentation and selected data records from this test are also included in the Appendix. Transducer locations are graphically illustrated on Figure 2A, Appendix.

TABLE 5

SUMMARY OF INSTRUMENTATION DATA FROM TEST 287

ACCELEROMETER RESULTS

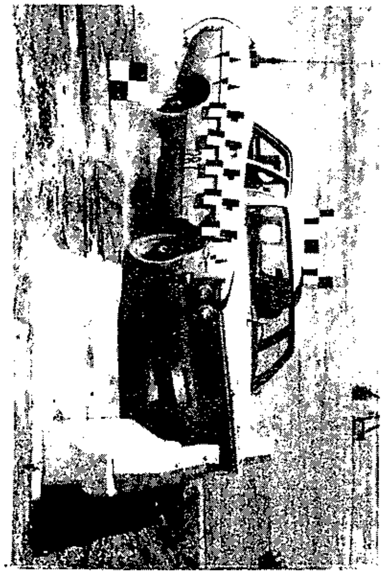
Accelerometer Location/Orientation	Deceleration Values Highest 50 ms Average Value of Deceleration in G's	Time After Impact In Seconds
1. Dummy Head (Vectorial resultant of data from long., lat., and vert. accelerometers)	30.4	.133-.183
2. Dummy Chest (longitudinal motion)	5.0	.150-.200
3. Vehicle - long. motion (Location B - Figure 2A)	7.8	.100-.150
4. Vehicle - lateral motion (Location D, Figure 2A) (Inside steel box filled with polyurethane)	15.8	.068-.118
5. Vehicle - lateral motion (Location D, Figure 2A) (On outer side of steel box)	14.6	.068-.118

VEHICLE IMPACTOGRAPH RESULTS (Peak Values)

Vertical (down units)	10	(up)	17
Longitudinal (forward units)	30		
Lateral (left units)	40	(right)	32

OTHER RESULTS

Gadd Severity Index	575
Max. Seat Belt Transducer Load (lbs.)	650

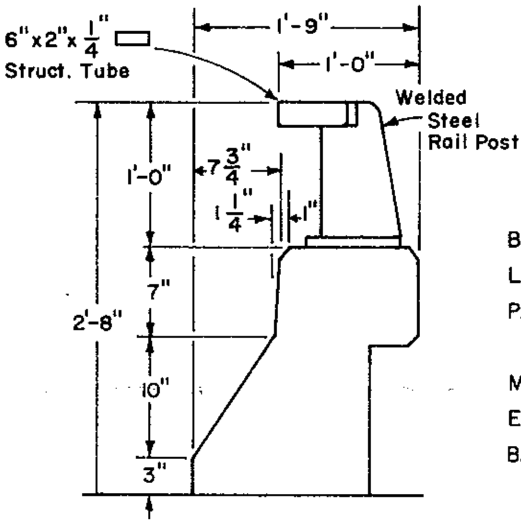


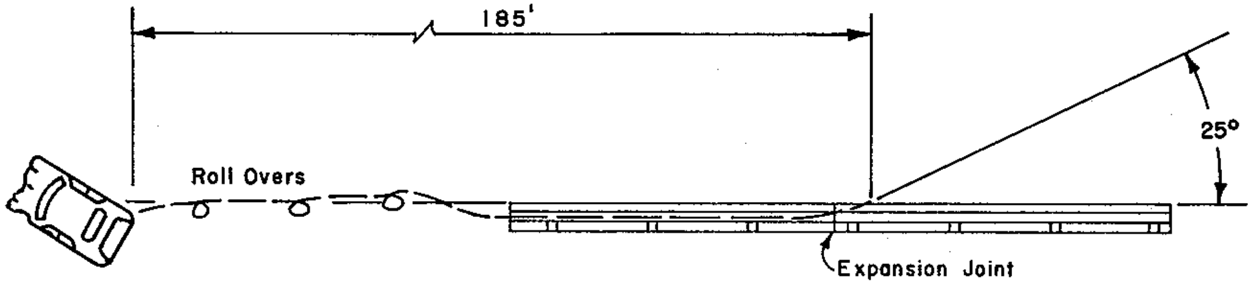
Impact +0.03 Sec.

I +0.13 Sec.

I +0.33 Sec.

I +0.68 Sec.





BARRIER TESTED	Modified Type 20 Bridge Rail		
LENGTH OF INSTALLATION		65' ±	
PASSENGER COMPARTMENT DECEL. (Highest 50ms average)	Long.	7.8	
	Lat.	14.6	
MAXIMUM VEHICLE RISE			Barrier Failure
EXIT ANGLE			Barrier Failure
BARRIER DAMAGE			Barrier Failure

TEST NO.	287
DATE	8/26/71
VEHICLE	1969 Dodge Sedan
SPEED	72 mph
IMPACT ANGLE	25°
VEHICLE WEIGHT (Incl./dummys & instrumentation)	4895 Lbs
DUMMY RESTRAINT	Lap Belt

C. Discussion of Test Results

1. Barrier performance

When the effectiveness of the Modified Type 20 design was evaluated, specific consideration was given to comparing the results of the tests reported herein with those obtained in similar tests of (1) the Standard Type 20 design [1] and (2) the vertical parapet Type 9 design [4] as shown in Table 6 below.

TABLE 6

SUMMARY OF PARAMETERS OF TESTS TO BE COMPARED

Test No.	Barrier	Approach Angle	Impact Velocity mph
281	Modified Type 20	5°	47
282	"	5°	54
283	"	5°	57
284	"	5°	62
285	"	10°	57
286	"	15°	65
287	"	25°	72
231	Standard Type 20	7°	45
232	"	7°	66
233	"	15°	64
235	"	25°	66
172	Type 9	25°	57

In the first four tests of this series (Test Nos. 281 - 284) the vehicle damage, although minor, was more than that sustained in similar tests of the standard Type 20 design (Test Nos. 231-232) (Figures 20 and 21).

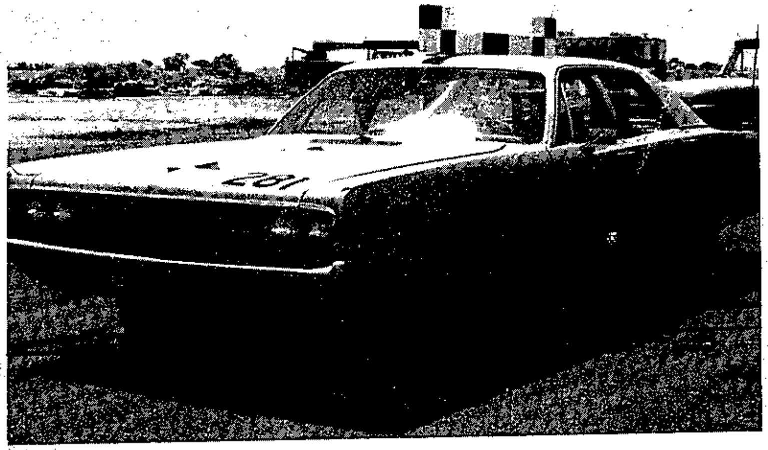


FIGURE 20 - VEHICLE DAMAGE
TEST 281 WITH MODIFIED
TYPE 20 BARRIER

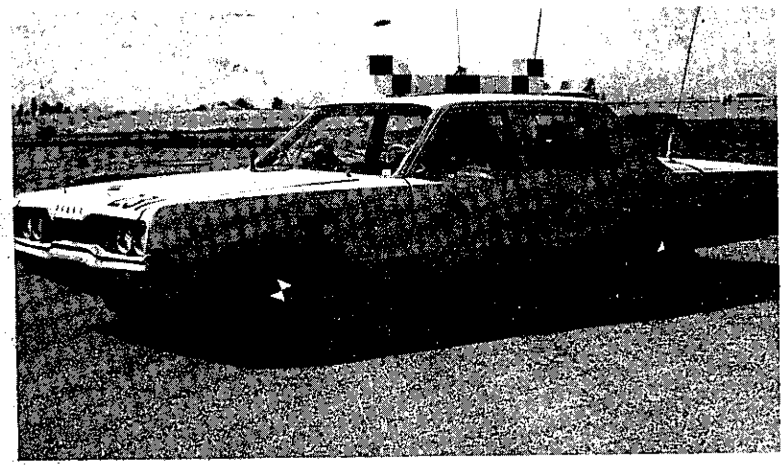


FIGURE 21 - VEHICLE DAMAGE
TEST 231 WITH STANDARD
TYPE 20 BARRIER

This increased damage, consisting essentially of sheet metal deformation, was attributed primarily to the 7 inch lower parapet/railing of the modified design. (Figure 22, Modified Type 20 design - Figure 23, standard Type 20 design).

FIGURE 22 - VEHICLE NEXT TO MODIFIED TYPE 20 BARRIER

FIGURE 23 - VEHICLE NEXT TO STANDARD TYPE 20 BARRIER

Analysis of the high speed data film from Tests 281 - 284 revealed that upon impact the test vehicle front bumper thrust over the top of the concrete parapet of the Modified Type 20 design. This permitted fender/railing contact prior to the initiation of vehicular redirection (Figure 24) whereas with the Standard Type 20 design the bumper contacted the concrete parapet and assisted in vehicular redirection (Figure 25).

FIGURE 24 - VEHICULAR IMPACT INTO MODIFIED TYPE 20 BARRIER TEST 281

FIGURE 25 - VEHICULAR IMPACT INTO STANDARD TYPE 20 BARRIER TEST 231

The 0.6 ft. average vehicle rise for the four low angle tests on the Modified Type 20 design was considerably less than the 1.3 ft. rise observed in the similar low angle tests on the Standard Type 20 design (Figures 26 and 27).

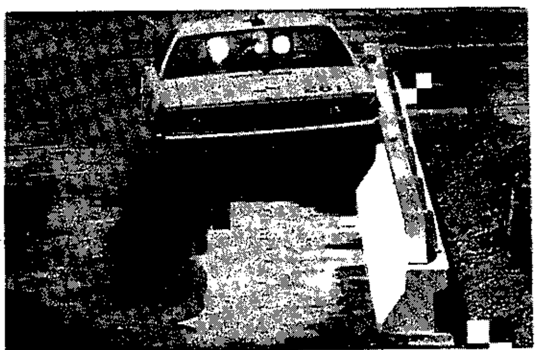


FIGURE 26 - VEHICULAR RISE ON MODIFIED TYPE 20 BARRIER TEST 281

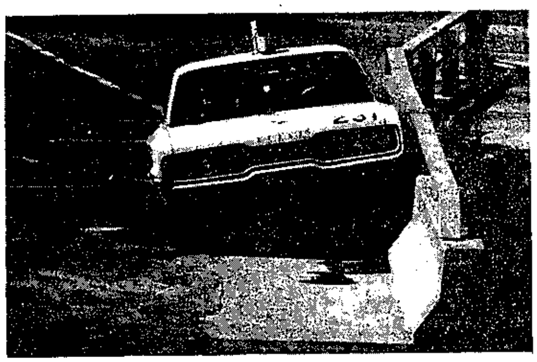


FIGURE 27 - VEHICULAR RISE ON STANDARD TYPE 20 BARRIER TEST 231

This lack of significant vehicular rise in the tests of the Modified Type 20 design is attributed to the indentation of the steel railing into the vehicle fender sheet metal which restricted the upward movement of the vehicle body. The vertical impact force was thus dissipated through greater compression of the vehicle suspension components and resistance of the barrier elements. In all tests conducted on "safety shape" parapets when impact angles were 10° or less the vehicle suspension and steering systems were not damaged and the vehicle was still operable (Figure 28). If a vertical concrete parapet had been used, it is quite likely that considerably more vehicle damage would have been sustained, and possibly the vehicle might have been rendered uncontrollable.

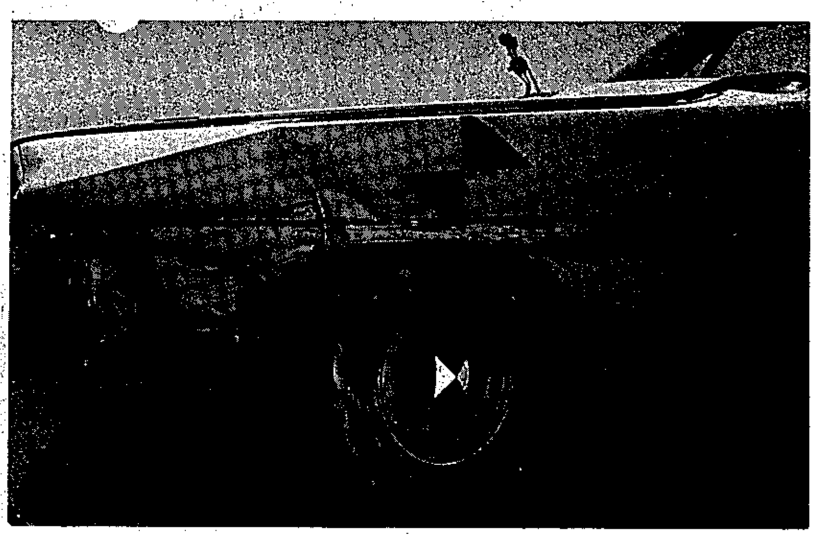


FIGURE 28 - VEHICLE DAMAGE
MODIFIED TYPE 20 BARRIER
TEST 285 (10° ANGLE)

However, at the wider 15° impact angle the effectiveness of the sloping "safety shape" parapet diminishes with regard to vehicle damage, and the results are comparable between the Modified Type 20 design (Test 286 - 15° - Figure 29), the standard Type 20 design (Test 233 - 15° - Figure 30), and to some extent a vertical concrete parapet, Type 9 design (Test 172 - 25° - Figure 31).

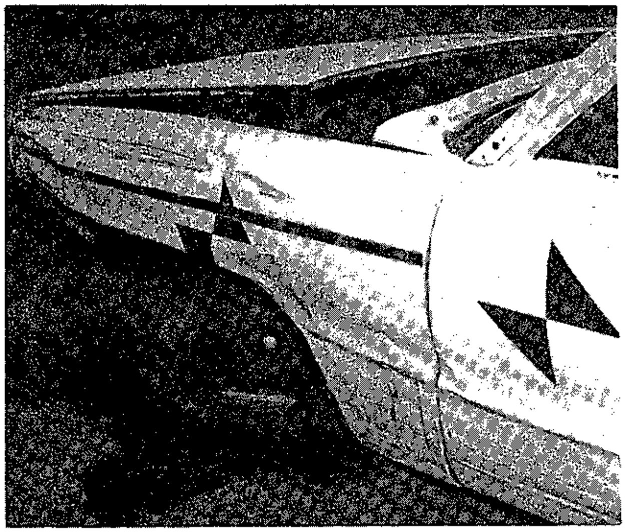


FIGURE 29 - VEHICLE DAMAGE FROM MODIFIED TYPE 20 BARRIER TEST 286 (15°)

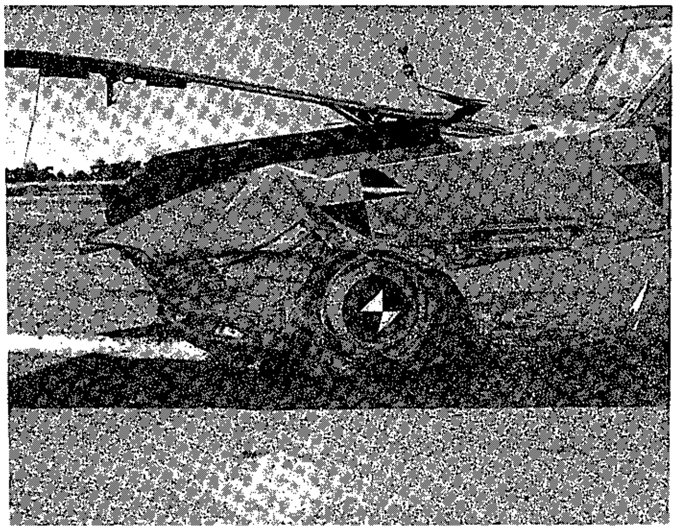


FIGURE 30 - VEHICLE DAMAGE FROM STANDARD TYPE 20 BARRIER TEST 233 (15°)

FIGURE 31 - VEHICLE DAMAGE FROM TYPE 9 BARRIER WITH A VERTICAL FACED PARAPET TEST 172 (25°)

When tested at the more severe 25 degree impact angle and a velocity of 72 mph (Test 287), the lightweight concrete parapet as designed was neither structurally nor geometrically adequate to retain the vehicle. At the 25 degree impact angle the 20-inch high parapet of the Modified Type 20 design allowed the vehicle front bumper and leading frame members to project over the parapet top and wedge between the parapet and the underside of the steel railing. Thus, as impact progressed, the steel railing was severely loaded both laterally and vertically prior to the initiation of any vehicular redirection. This impact loading, transmitted in part to the railing support posts and the concrete parapet, was beyond the structural capabilities of these barrier components. In similar large angle impacts into the standard Type 20 design (Test 235) a vehicular redirection force is applied by the parapet at the vehicle wheel/frame prior to serious vehicle/railing involvement. Also, considerable impact energy is absorbed or dissipated through vehicular deformation during this significant contact with the parapet.

A concrete mix design, reinforcement and post anchorage system could be developed for the Modified Type 20 design that would be structurally adequate to withstand the impact forces and retain the vehicle. However there are other factors which must be considered such as economics, vehicular redirection with low deceleration rates and, with bridge rails, barrier width and weight. A more comprehensive research effort with additional crash tests would be required to evaluate these factors. Based on the results of the tests conducted in this study it was determined that the geometry of the modified design was not as effective as the standard Type 20 design and further developmental work on the modified design was therefore not warranted.

After reviewing all crash tests on the modified and standard Type 20 Bridge Rail, the Bridge Department made the decision to adopt an all concrete bridge rail called "Concrete Barrier - Type 25. Details for this design, which will be included in the 1973 Standard Plans, are shown on Figure 32. The concrete parapet height for the standard Type 20 Bridge Rail had been set at 27 inches to be compatible with existing standard approach guardrail design heights. The Type 25 design, however, with a concrete parapet height of 32 inches includes an all concrete approach barrier which is a continuation of the main bridge barrier. The Type 25 design was selected in preference to the Type 20

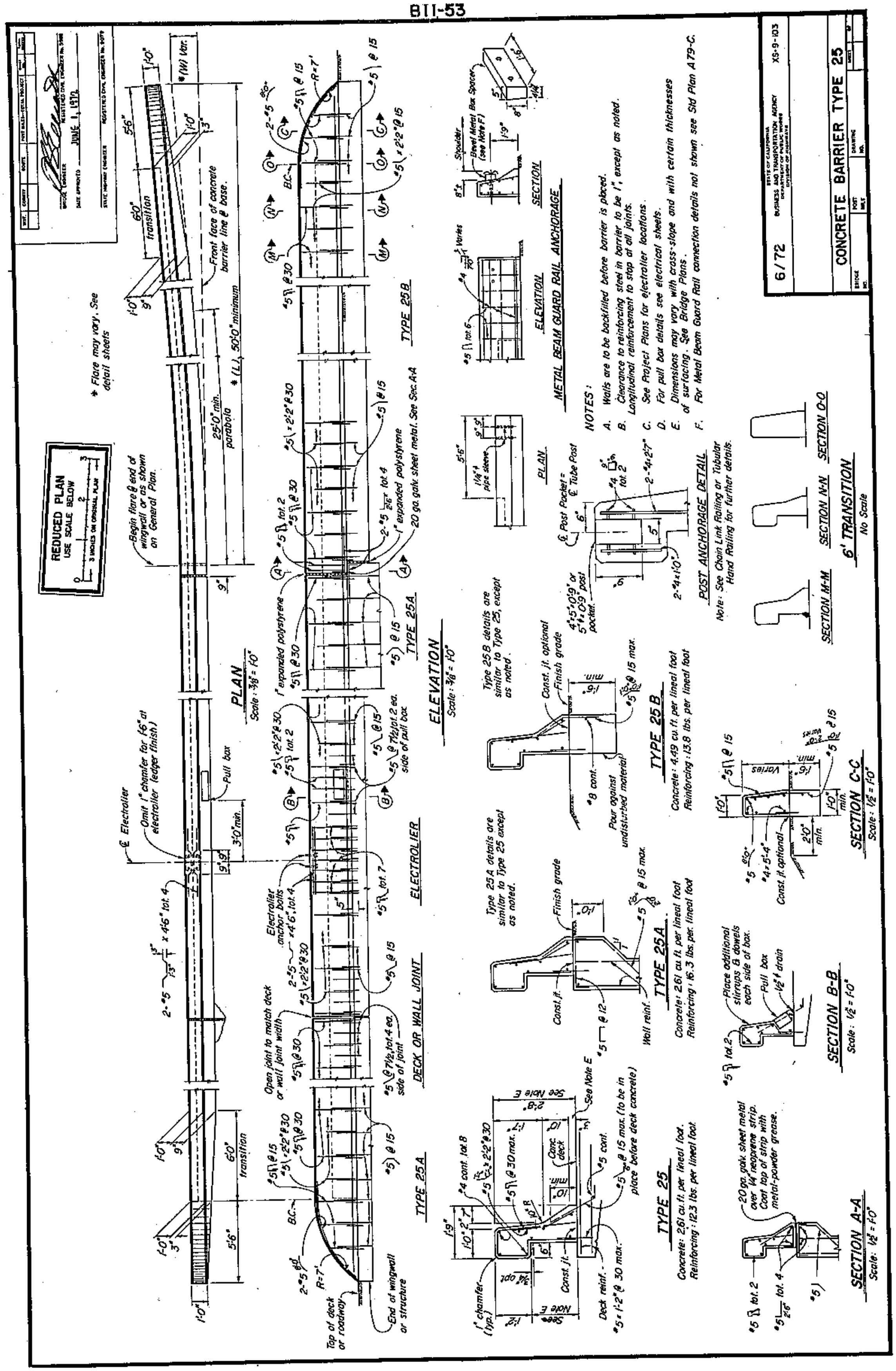


FIGURE 32

DETAILS OF CONCRETE BARRIER TYPE 25
(Reduced plan - not to scale)

design for the following reasons:

a. The Type 25 design should be less expensive to construct.

b. The "see-through" properties should be better on the Type 25 barrier with an over-all height of 32 inches as compared with an over-all height of 39 inches for the standard Type 20 barrier. Sight distance over a barrier becomes especially critical on curves and grades, particularly at on-and off-ramps.

c. The "safety shape" parapet minimizes damage to vehicles during impacts, but a steel rail above the concrete parapet (as used in the modified and standard Type 20 design) may increase vehicle damage for some impacts.

d. The Type 25 barrier will be compatible with the Type 50 Concrete Median Barrier which is being used extensively.

Additional crash tests did not seem warranted since previous tests showed the effectiveness of the Type 50 Concrete Median Barrier which has the same profile as the traffic side of the Type 25 barrier. In addition, numerous subsequent crash tests on barriers which incorporate the "safety-shape" parapet have confirmed its effectiveness.

2. Instrumentation Data Analysis

One of the most desirable attributes of a good bridge rail design is its ability to inhibit serious injuries to occupants of an impacting vehicle while retaining and redirecting the vehicle. It is impossible to measure this quality precisely; however, data from accelerometers and a mechanical Impactograph mounted on the vehicle and accelerometers in the dummy occupant provided a possible means of evaluation. Data from the vehicle accelerometers in each test are compared in Table 7 with the deceleration limits established by researchers at Cornell University [6]. The Cornell values are considered to represent the threshold of severe injuries.

The 50 millisecond highest average deceleration time duration used by the researchers in this report differs from the time interval originally suggested by the

Cornell researchers. In analyzing our transducer records from many past impact tests, it was determined that the maximum intensity portion of most deceleration pulses occurred within the 50 millisecond time interval. If the high deceleration record spikes in the 50 ms period were averaged over a 200 ms period or over the entire event from start to stop, they would frequently show a much lower level of deceleration that could be misleading with respect to injury potential for passengers Reference [1] contains a detailed explanation of this choice.

Although the Cornell table is useful for comparing the relative severity of vehicle impacts, it does not relate directly to specific occupant injuries. Occupant injuries are directly related to the decelerations and forces exerted on various parts of the anatomy as a body strikes the interior surfaces of the decelerating vehicle. Concurrent decelerations on the vehicle may be quite different. Data from accelerometers mounted in the chest and head of the dummy occupant are shown in Table 8. The maximum recorded dummy seat belt load is also shown in the table.

Data from accelerometers mounted in the head cavity of the dummy occupant were used to compute the Gadd Severity Index [7] which is directly related to concussion type head injuries. This is one of the most frequent and serious injuries occurring in vehicle accidents. The Gadd Severity Index is $\int_{t1}^{t2} a^{2.5} dt$ where "a" is the resultant head decleration (vectorial sum of long., lat., and vert. head decelerations), dt is 0.0025 seconds, and t1 to t2 spans the 50 millisecond interval in which the maximum average resultant deceleration occurs. The Index is related to a curve developed at Wayne State University showing the tolerance of the head to deceleration as a function of deceleration magnitude and duration. More specifically, the curve was limited to blows on a minimum area of one square inch on the forehead portion of the skull. Blows on an area smaller than one square inch, which might otherwise be nonfatal, could produce a fatality due to penetration of the skull.

Deceleration forces exerted on the chest of the dummy and loads on the lap belt were used to compare crash severity but were not rated against any standard to ascertain occupant injuries.

Data from mechanical Impactographs mounted on the floorboard of the test vehicles is shown in Table 9. This data also was used to generally compare crash severity rather than to assess occupant injury or survivability.

In summary, the deceleration limits suggested by Cornell establish the relative survivability of the vehicle passenger compartment as a whole whereas the Gadd Severity Index provides a specific tolerance level for determining fatal head injuries. The Gadd Index, however, is less useful in determining the over-all crash severity because of significant variations which may occur as the result of the physical makeup of the dummy and the vehicle interior, the dummy restraints in use, and even small differences in the configuration of the dummy when it strikes the vehicle interior. Dummies such as ours have not been proven completely reliable in simulating real passenger response during impacts. Referring to Table 7 note that in Tests 281 - 284 the values of vehicle deceleration are not critical, even for unrestrained occupants, when judged by the Cornell table. However, in Test 287 the decelerations when judged by this standard were excessively high for all types of occupant restraints. In Table 8 the Gadd Severity Index indicates a small chance of serious head injury to the dummy for Tests 281 - 284. The Index for Test 287, although well below the lower threshold for fatal head injury (1000), was significant enough to indicate that the occupants were in danger of serious injuries. This hazard was much increased due to the rolling of the vehicle in this test which crushed the passenger compartment.

A comparison of deceleration data obtained from the first four tests (Tests 281 - 284) as shown on Tables 7, 8 and 9 indicates inconsistency (possibly too high) in the values for Test 283. The vehicle accelerometer values generally increased in a logical sequence relevant to the increase in vehicular velocity. However, the Impactograph recorded a disproportionate longitudinal deceleration in Test 283. The dummy accelerometer values were also disproportionately higher for Test 283. An analysis of the data film failed to reveal any specific reason for the higher Impactograph values. However, it appeared that the higher dummy accelerometer values were the result of dummy kinematics rather than impact severity. In Test 283 the dummy was positioned slightly more upright and to the right in the driver's seat than usual. On impact, the dummy was propelled down and to the left, striking the door below the window sill first with its left shoulder and then with its head. This is in contrast to the usual dummy movement observed in the other 5 degree tests where the dummy was propelled up and to the left and struck the door post virtually simultaneously with its left shoulder and head.

TABLE 7

SUMMARY OF VEHICLE DECELERATIONS

ACCELEROMETER RESULTS

Test No.	Impact Speed (mph)	Impact Angle (Degrees)	Accelerometer Location*	Highest 50 ms Avg. Value of Deceleration (G's) Lateral	Longitudinal
Modified Type 20 Bridge Rail					
281	47	5°	B	1.7	1.4
282	54	5°	B	1.2	0.3
283	57	5°	B	2.6	1.5
284	62	5°	B	3.5	1.6
287	72	25°	D (lat.) B (long.)	15.8	7.8
Type 20 Bridge Rail (Reference [1])			(Avg. values from several accelerometers)		
232	66	7°		4.8	No data
234	64	7°		4.8	Less than 1
235	66	25°		13.0	14.8
Cornell Table - Recommended Max. Values - For All Impact Speeds & Angles					
Unrestrained Passengers				3	5
Passengers with Lap Belts				5	10
Passengers with Lap Belts & Shoulder Harnesses				10	25

Vehicle Wt. for the Modified Type 20 Tests was 4830-4890 lbs.

For the Type 20 Tests the vehicle weight was 4900-4980 lbs.

*See Figure 2A

TABLE 8

SUMMARY OF DUMMY DECLERATIONS AND SEAT BELT LOADS

Test No.	Impact Speed (mph)	Impact Angle (Degrees)	Highest 50 Millisecond Average Values of Decelerations: Dummy's Chest Longitudinal (G's)	Highest 50 Millisecond Average Values of Decelerations: Dummy's Head Resultant (G's)	Gadd Severity Index	Max. Lap Belt Load (lbs.)
281	47	5°	1.7	6.1	18	130
282	54	5°	1.3	5.2	10	0
283	57	5°	2.6	17.2	175	240
284	62	5°	1.7	9.5	73	150
287	72	25°	5.0	30.4	575	650

NOTE: 1. The deceleration of the dummy's head is the resultant of the long., lat., and vert. values of deceleration.

2. The value of the Gadd Severity Index which is the lower threshold of fatal head injuries is 1000.

All vehicle decelerations for Tests 281 - 284 were based on data from the longitudinal and lateral accelerometers mounted on the floorboard at the vehicle center of gravity (horizontal plane only). Recordings from accelerometers mounted in or on a polyurethane foam filled steel box, which was also secured to the vehicle floorboard were very similar and were not processed (accelerometer locations shown on Figure 2A, Appendix). For Test 287 the lateral deceleration reported was the average of the values recorded by the accelerometers mounted in and on the polyurethane filled steel box. The curves from these accelerometers were very similar. The lateral deceleration record from the floorboard mounted accelerometer at the vehicle's center of gravity was not used due to a malfunction of the accelerometer. Consequently, a valid comparison of data from accelerometers on different types of mountings could not be made. Referring to Table 7, it can be seen that the values of vehicular deceleration for tests 232, 234, and 235 (Standard Type 20 design) were similar to those for Tests 281 - 287 (Modified Type 20 design). Decelerations in all cases were low for impact angles of 5 to 7 degrees and high for angles of 25°.

Selected deceleration records from Tests 284 and 287 are contained in the Appendix.

Table 9 summarizes the readings from the mechanical Impactograph installed on the floorboard behind the front seat of the vehicles used in all of the tests in this series.

TABLE 9
SUMMARY OF VEHICLE IMPACTOGRAPH RECORDINGS (Peak Values)

Direction	Test 281 47/5°	282 54/5°	283 57/5°	284 62/5°	285 57/10°	286 65/15°	287 72/25°
Vertical (down-units)	5	5	5	6	4	8	10
Longitudinal (forward-units)	3	2	7	4	4	5	30
Lateral (left-units)	6	6	7	7	9	11	40

As mentioned elsewhere in this report, these Impactograph values are not "G" forces, but rather, traces of the relative severity of impact as measured on the test vehicle. The records are reproduced in the Appendix, Section V.E, Figures 11-A through 13-A. The Impactograph values indicate that at impact angles less than 15°, the severity of impact in this test series increased only slightly in the lateral direction relative to the impact velocity with no appreciable difference noted in the longitudinal and vertical recordings. Overall impact severity with this barrier design appears to be more a function of the angle of impact, as illustrated by the substantially higher values obtained in Tests 286 (15°) and 287 (25°), rather than a function of impact speed (Tests 281 - 284).

The vehicle accelerometer records verify this with increasing "G" forces recorded for Tests 281 - 284 (5°) in the lateral direction; no appreciable difference in the longitudinal direction and substantially higher forces recorded in both directions for Test 287 (25°).

IV. REFERENCES

1. Nordlin, E. F., Woodstrom, J. H., and Hackett, R. P., "Dynamic Tests of the California Type 20 Bridge Barrier Rail, Series XXIII", California Division of Highways, October 1970.

2. Nordlin, E. F., Field, R. N., and Stoker, J. R., "Dynamic Tests of Concrete Median Barrier, Series XVI", California Division of Highways, August 1967.

3. Lundstrom, L. C., et al, "A Bridge Parapet Designed for Safety", General Motors Proving Grounds, presented at the 44th Annual HRB Meeting, January 1965.

4. Nordlin, E. F., Ames, W. H., and Hackett, R. P., "Dynamic Tests of Type 9 Bridge Barrier Rail and Type 8 Bridge Approach Guardrail, Series XVII", California Division of Highways, June 1969.

5. Highway Research Board on Guardrails and Guide Posts, "Proposed Full-Scale Testing Procedures for Guardrails", Circular 482, September 1962.

6. "Highway Barrier Analysis and Test Program", Summary Report for period July 1960 - July 1961, Cornell Aeronautical Laboratory Report No. VH-1472-V-3, July 1969.

7. "10th Stapp Car Crash Conference - Proceedings", November 8-9, 1966, published by Society of Automotive Engineers, Inc. Paper 660793 by Charles W. Gadd, "Use of Weighted-Impulse Criterion for Estimating Injury Hazard"; Paper 660803 by Alan M. Nahum, M. D., Arnold W. Siegel, and Stanford B. Trachtenberg, M. D., "Causes of Significant Injuries in Nonfatal Traffic Accidents".

V. APPENDIX

A. Crash Car Equipment

Following is a description of the modifications made to crash cars prior to impact tests. The method of controlling the car remotely is also described.

1. The test vehicle gas tank was disconnected from the fuel supply line, drained and refilled with water. A one gallon safety gas tank was installed in the trunk compartment and connected to the fuel supply line.

2. Three wet-cell storage batteries (6, 8, and 12 volt) were mounted on the floor of the rear seat compartment. They supplied power for the remote control equipment.

3. A solenoid-valve actuated CO_2 system was connected to the brake line for remote braking. With 700 psi in the accumulator tank, the brakes could be locked in less than 100 milliseconds after activation.

4. The ignition system was connected to the brake relay in a failsafe interlock system. When the brake system was activated, the vehicle ignition was switched off. Also, any loss of steering control by reason of a failure of the radio transmitting or receiving systems would automatically energize the brake relay, thus cutting the vehicle ignition and braking the vehicle to a stop.

5. The accelerator pedal was linked to a small electric motor which, when activated, opened the throttle. The motor was activated by a manually thrown switch mounted on the top of the rear fender of the test vehicle.

6. Steering was mechanically accomplished with a 400 inch-ounce stepping motor through a V-belt driven pully attached to the steering shaft. The stepping motor was mounted on a bracket secured to the floor-board of the front seat compartment and activated through the remote radio tuned relay system for right or left turns.

7. A radio control receiver, tone actuated relays, steering pulse and handi-talkie radio were mounted on a chassis bolted to the floorboard of the trunk compartment. Whip antennas for the radio receivers were mounted on the vehicle's rear fender.

8. A micro switch was mounted below the front bumper and connected to the ignition system. A trip line installed 40 feet from impact triggered the switch; thus opening the ignition circuit and cutting the vehicle motor prior to impact.

9. The left front and left rear tires were painted to delineate wheel climb on the parapet face (front-red, rear-green).

B. Photo-Instrumentation

Data film was obtained by high speed cinematography through the use of seven Photosonic 16mm cameras (250-400 frames per second). These cameras were located on tripods to the front, rear, and sides of impact and on a tower 35 ft. above impact. All cameras were electrically actuated from a central control console (Figure 1A). An eighth Photosonic camera was located in the test vehicle to record the kinematics of the anthropometric dummy. This camera was triggered by a tether-line actuated switch mounted on the rear bumper of the test vehicle.

All cameras were equipped with timing light generators which exposed reddish timing pips on the film at a rate of 1000 per second. The pips were used to determine camera frame rates and to establish time-sequence relationships. Additional coverage of the impacts was obtained by a 70mm Hulcher operating at a rate of 20 frames per second, and a 35 mm sequence camera operating at 20 frames per second. Documentary coverage of the tests consisted of normal speed cine-photography and still photographs taken before, during, and after each impact. Data reduction from the high-speed cinematography was accomplished on a Vanguard Motion Analyzer. Procedures taken to instrument the crash vehicle and the test site to assist in the reduction of data are listed below:

1. Targets were attached to the vehicle body, the face of the barrier, and at ground locations to the front and rear of the barrier.

2. Flashbulbs, mounted on the test vehicle, were used to establish (a) initial vehicle/barrier contact and (b) the application of the vehicle's brakes.

3. Five tape switches were laid on the ground perpendicular to the vehicle path leading into the point of impact. Placed at 10-foot intervals immediately in front of impact, the switches were actuated sequentially by the tires of the test vehicle, thus triggering a series of flashbulbs. The flashbulbs were in the field of view of all the data cameras and were used to correlate cameras to collision events and to determine the impact velocity.

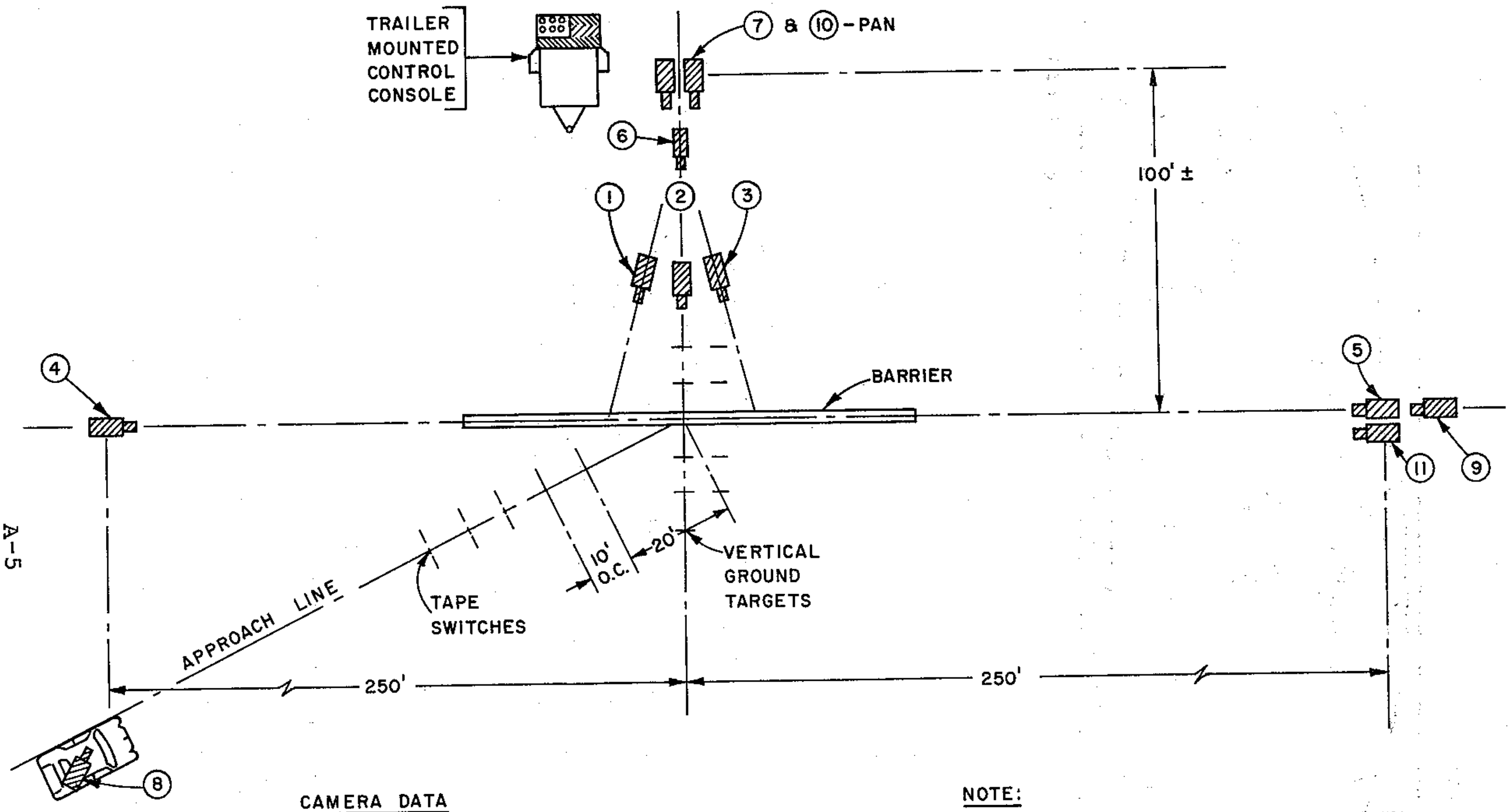
C. Electronic Instrumentation

A total of eight Statham accelerometers, of the unbonded strain gage type, were used for deceleration measurement. Of these, four were mounted in the chest and head cavities of the anthropometric dummy occupant and four were mounted on the floorboard of the test vehicle. In addition one seat belt transducer was installed on the dummy lap belt. Data from these nine transducers were transmitted through a 1000 ft. Belden #8776 umbilical cable that ran from a rear mounting on the test vehicle to a 14 channel Hewlett Packard 3924C magnetic tape recording system. This recording system was mounted in an instrumentation trailer located in the test control area. Figure 2A shows the location of the transducers in the test vehicle. Three pressure activated tape switches were mounted on the pavement at fixed intervals in the vehicle approach path. When activated by the test vehicle's tires, these switches produced sequential impulses which were recorded with the transducer signals on the tape recorder. Concurrently a 100 millisecond time cycle signal was impressed on the tape. All of the tape recorder data were subsequently played back through a Visicorder which produced an oscillographic trace (line) on paper. Each paper record contained a curve of data from one of the nine transducers, the signals from the three tape switches, and the 100 millisecond time cycle marking. Some of the records of accelerometer data had high frequency spikes which made analysis difficult. Therefore, the original test data was filtered at 100 Hertz with a Krohn-Hite filter. The smoother resultant curves gave a good representation of the over-all vehicle deceleration without significantly altering the amplitude and time values of the deceleration pulse. Transducer records filtered at 100 Hertz from Tests 284 and 287 are contained in the Appendix. The records from Tests 281 - 283 all showed low values similar to those for Test 284; hence they were not included. No electronic data were available for analysis of Tests 285 and 286.

It should be noted that in oblique angle impacts, the dummy's torso and head have a tendency to twist (rotate about the hips) axially during vehicular redirection. Hence, the orientation of the dummy's accelerometers, particularly those mounted in the head cavity, may not always be consistent with those mounted on the vehicle; i.e., the longitudinal accelerometer in the dummy may have recorded lateral and vertical components of deceleration with respect to the vehicle axes. The Gadd Severity Index and the maximum average values of deceleration over a 50 millisecond period were found by inserting data points, taken at a time interval of 0.0025 seconds, into a digital computer program. A summary of the dummy loads and decelerations recorded during the tests reported herein are tabulated on Table 8.

A mechanical Impactograph was secured to the test vehicle floorboards behind the right front seat. The mechanical styluses of this device records lateral, longitudinal, and vertical impact forces. The record produced is not as accurate as that from the transducers as it is insensitive to the higher frequencies. However, it does provide a comparison of impact severity and serves as a back-up system in case of failure of the electronic system. A summary of the Impactograph recordings obtained from the tests reported herein are tabulated on Table 9.

A brief analysis of the instrumentation data obtained from the tests reported herein is included in Section III-C-2 of this report.



CAMERA DATA

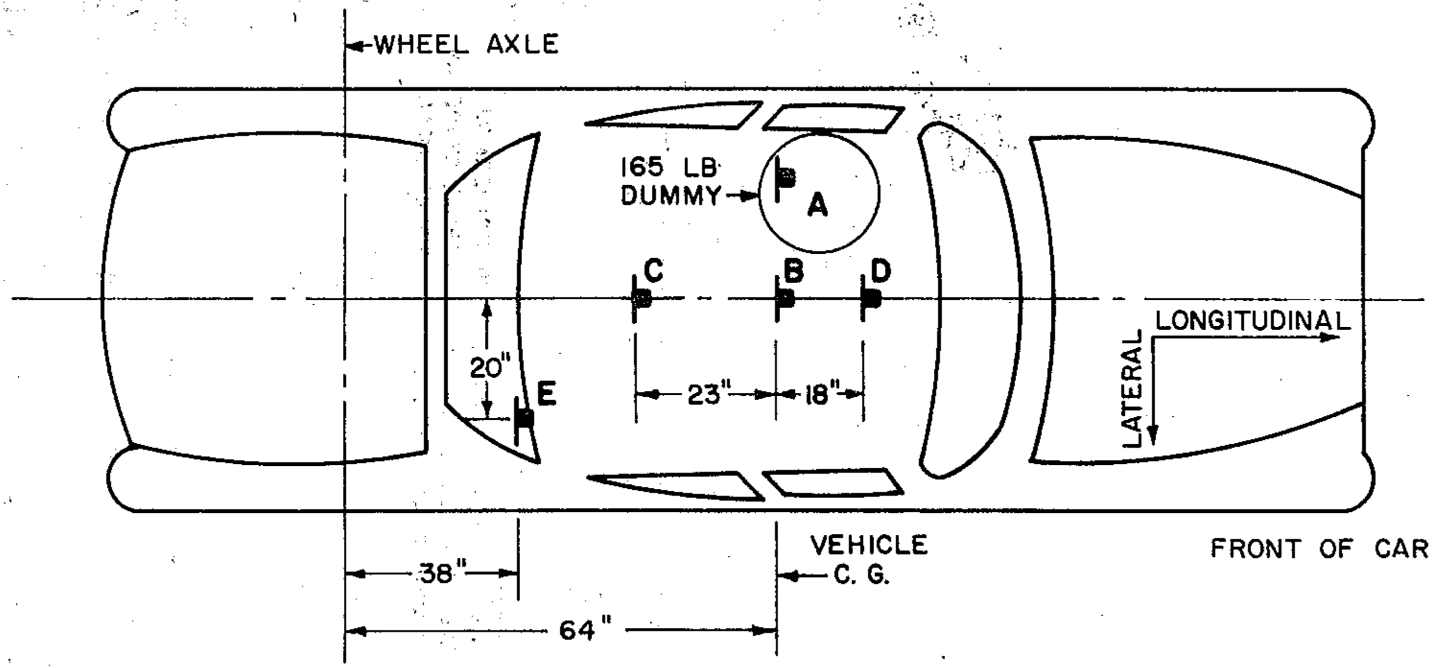
1 2 3 PHOTO - SONICS, 13.0 MM LENS, 380 FPS,* MOUNTED ON 35' TOWER AND ORIENTED TO COVER THE AREAS INDICATED ABOVE.

4 5 PHOTO - SONICS, 4" LENS, 380 FPS.
6 PHOTO - SONIC, 2" LENS, 380 FPS.
7 PHOTO - SONIC, 2" LENS, 380 FPS.
8 PHOTO - SONIC, 5.3 MM WIDE ANGLE LENS, 200 FPS, INSIDE TEST CAR.
9 HULCHER, 70MM SEQUENCE CAMERA, 12" LENS, MOUNTED ABOUT 12' HIGH ON SCAFFOLD.
10 BOLEX, 1" LENS, 24 FPS.
11 HULCHER, 35 MM SEQUENCE CAMERA.

*FRAMES PER SECOND

NOTE:
CAMERAS 4 AND 5 HAVE THEIR HORIZONTAL AXES ALIGNED ON A PLANE 5' ABOVE GRADE AS MEASURED AT THE DESIRED POINT OF IMPACT.

FIGURE 1-A
PHOTO-INSTRUMENTATION PLAN



Accelerometer Location			Orientation
All tests	A	Dummy's Head	Longitudinal
All tests	A	Dummy's Head	Lateral
All tests	A	Dummy's Head	Vertical
All tests	A	Dummy's Chest	Longitudinal
All tests	B	Vehicle Floor	Longitudinal
All tests	B	Vehicle Floor	Lateral
Tests 281-284	C	Vehicle Floor - in Urethane	Lateral
Test 287	D	Vehicle Floor - in Urethane	Lateral
Tests 281-282	C	Vehicle Floor - in Urethane	Longitudinal
Tests 283-284	C	Vehicle Floor - on Outside of Steel Box	Lateral
Test 287	D	Vehicle Floor - on Outside of Steel Box	Lateral

Seat Belt Transducer

All tests - Location A - Across Dummy's Lap.

Impact-O-Graph

All tests - Location E - Vehicle floor

NOTE: Location A (for acelerometers) is on the back of the head or in the chest cavity of the dummy; Location B is on a steel angle bracket welded to the floor at the vehicle center of gravity; Locations C and D are in or on a steel box filled with polyurethane foam and mounted on the vehicle floor.

FIGURE 2A - VEHICLE INSTRUMENTATION.

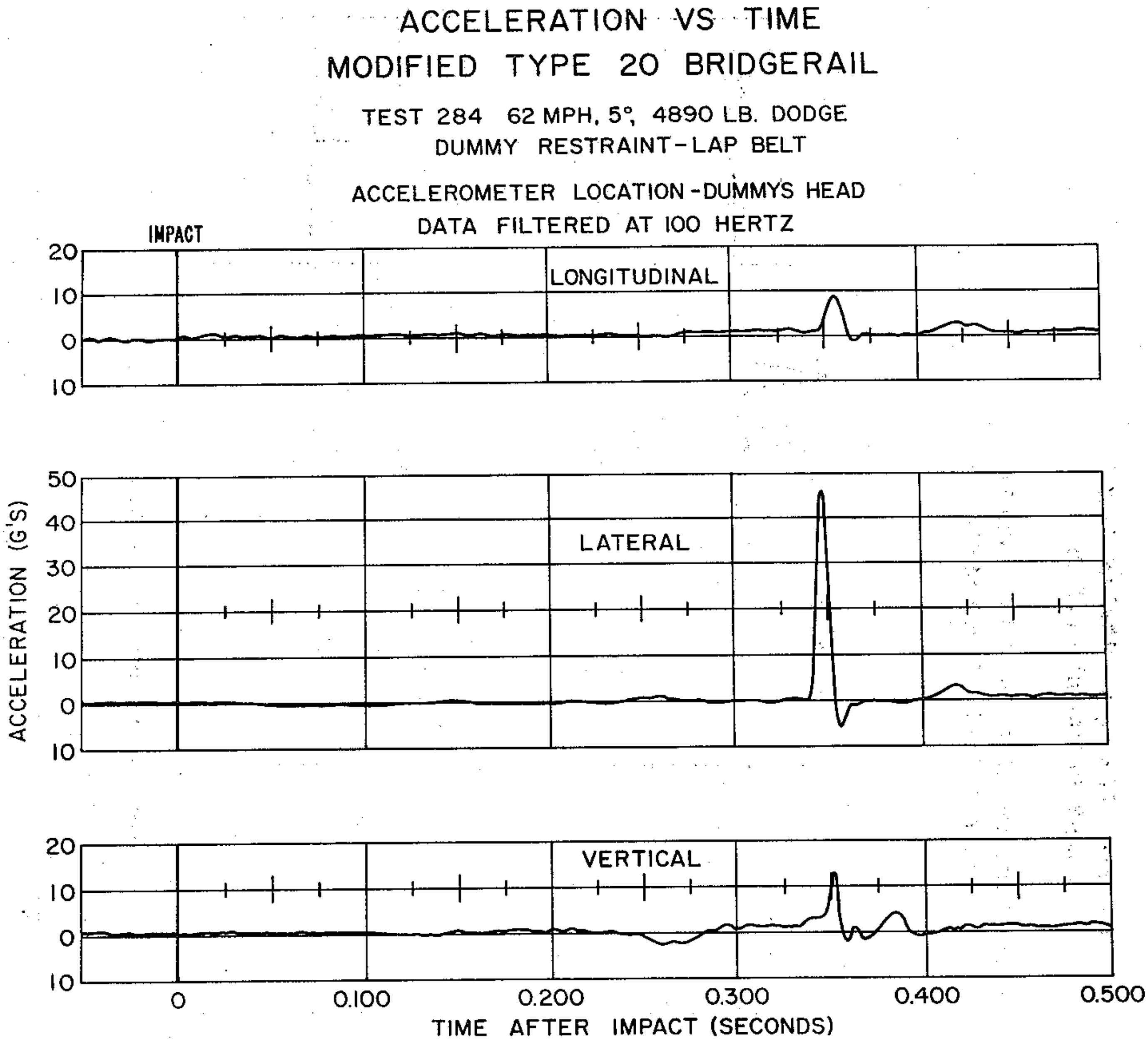


FIGURE 3-A
ACCELEROMETER RECORDS - DUMMYS HEAD
TEST 284

MODIFIED TYPE 20 BRIDGERAIL

TEST 284 62 MPH, 5°, 4890 LB. DODGE
DUMMY RESTRAINT - LAP BELT

ACCELEROMETER LOCATION - DUMMYS CHEST
DATA FILTERED AT 100 HERTZ

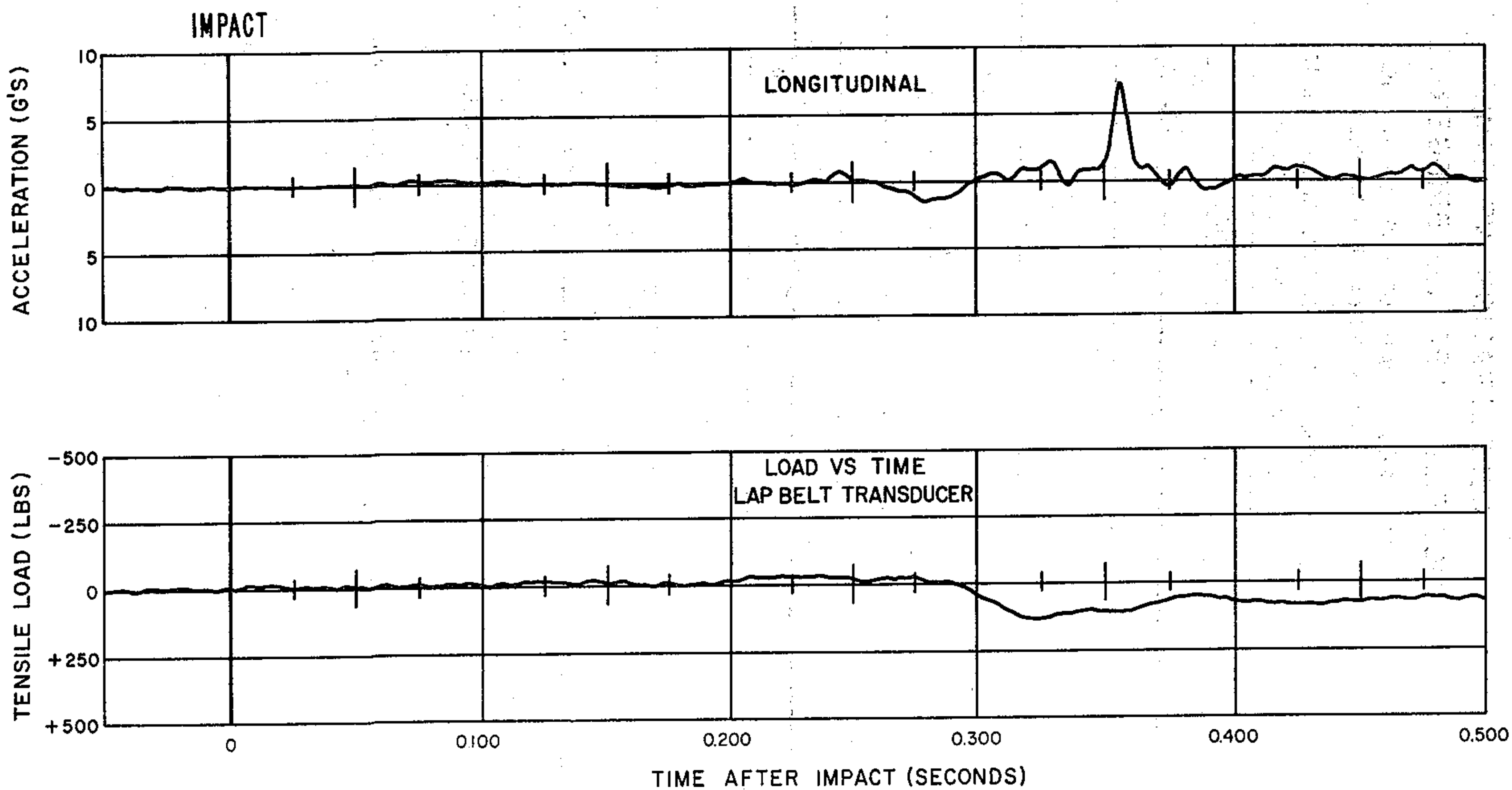


FIGURE 4-A
ACCELEROMETER RECORDS - DUMMYS CHEST
TEST 284

ACCELERATION VS TIME

MODIFIED TYPE 20 BRIDGERAIL

TEST 284   62 MPH, 5°, 4890 LB. DODGE
DUMMY RESTRAINT - LAP BELT

ACCELEROMETER LOCATION- VEHICLE FLOOR
DATA FILTERED AT 100 HERTZ

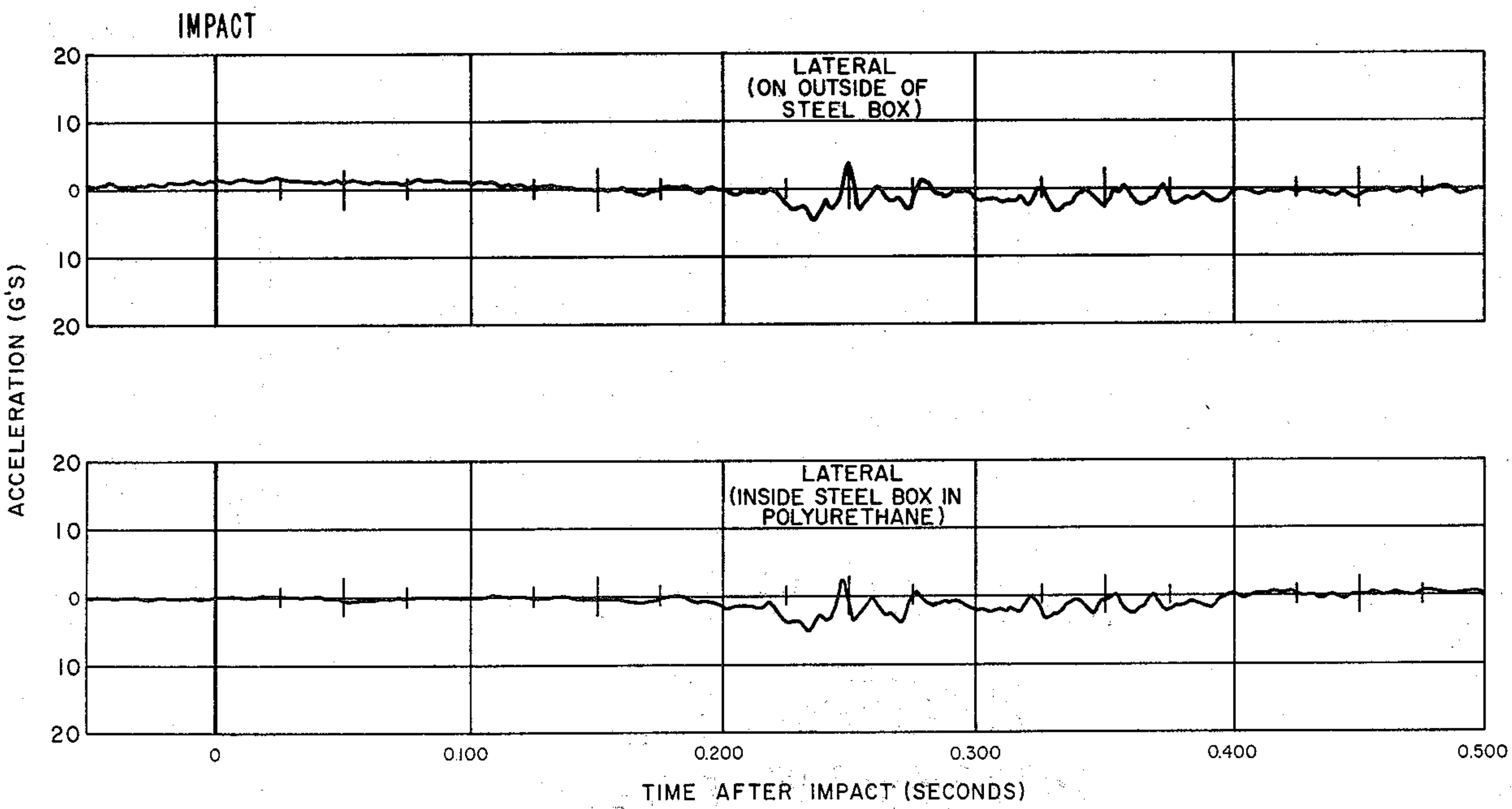


FIGURE 5-A
ACCELEROMETER RECORDS - VEHICLE FLOOR
TEST 284

ACCELERATION VS TIME

MODIFIED TYPE 20 BRIDGERAIL

TEST 284 62 MPH, 5°, 4890 LB. DODGE
DUMMY RESTRAINT - LAP BELT

ACCELEROMETER LOCATION - VEHICLE FLOOR AT C.G.
DATA FILTERED AT 100 HERTZ

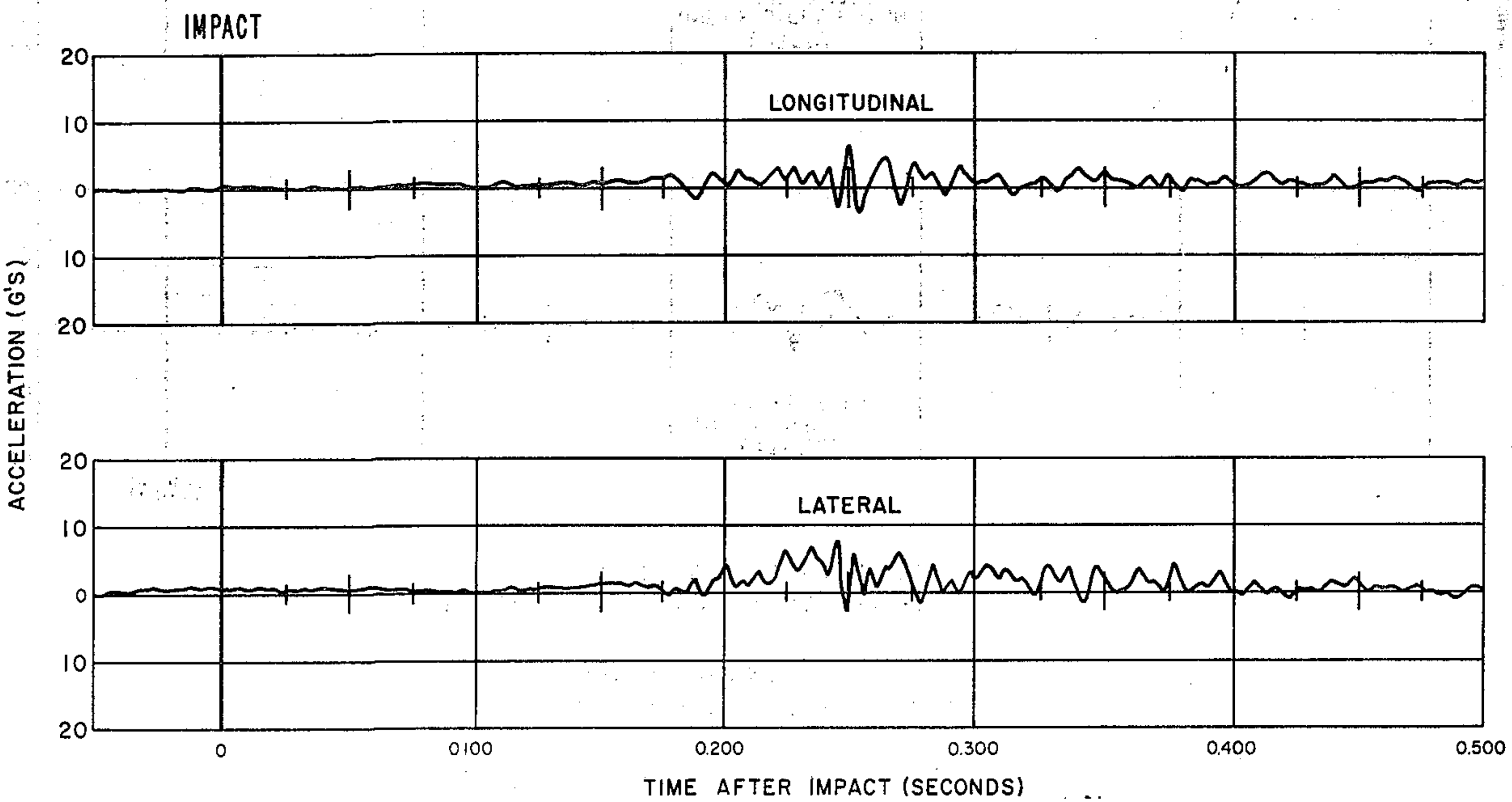


FIGURE 6-A
ACCELEROMETER RECORDS - VEHICLE C.G.
TEST 284

ACCELERATION VS TIME
MODIFIED TYPE 20 BRIDGERAIL

TEST 287 72 MPH, 25°, 4830 LB. DODGE
DUMMY RESTRAINT-LAP BELT

ACCELEROMETER LOCATION-DUMMYS HEAD
DATA FILTERED AT 100 HERTZ

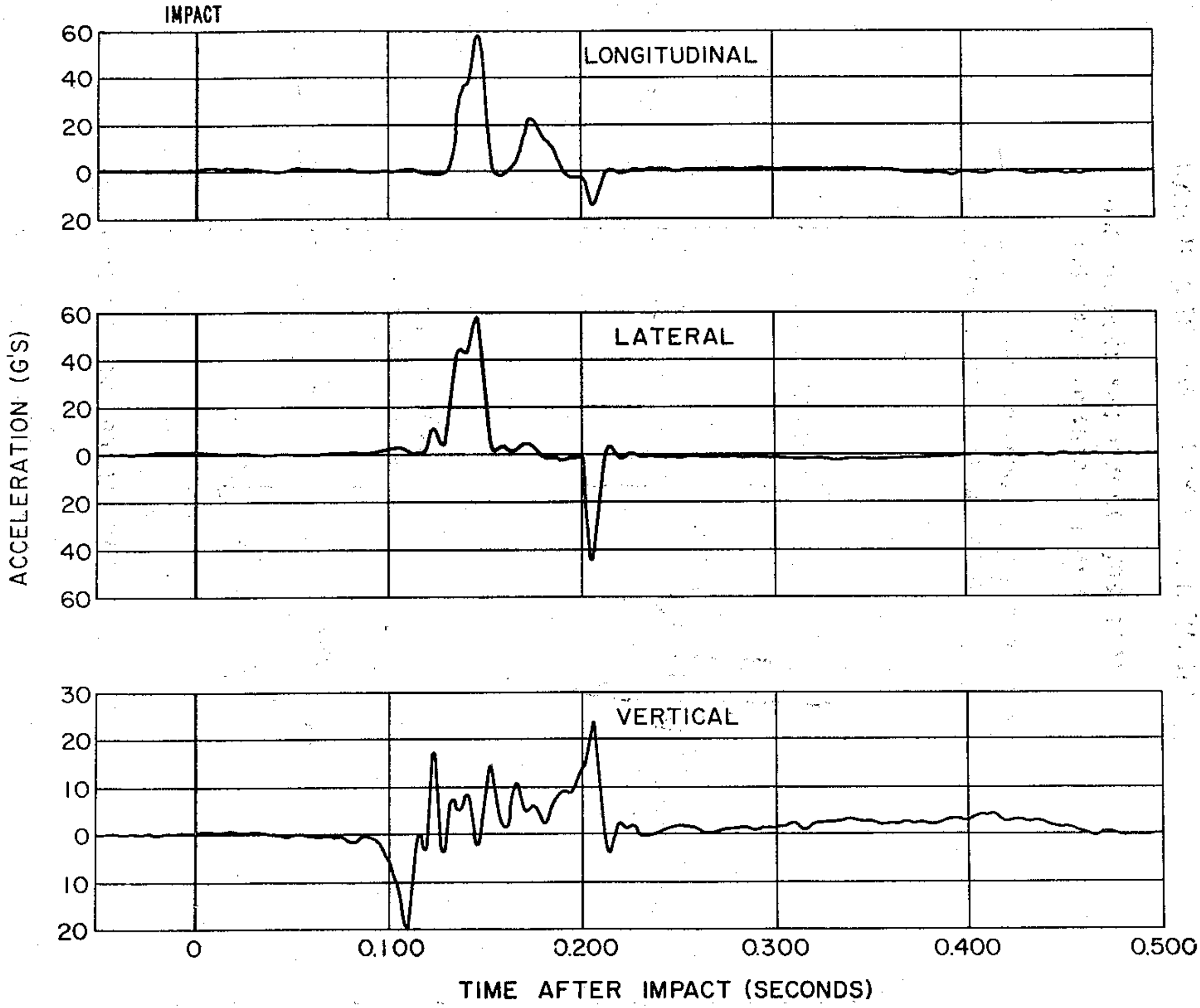


FIGURE 7-A
ACCELEROMETER RECORDS - DUMMYS HEAD
TEST 287

ACCELERATION VS TIME

MODIFIED TYPE 20 BRIDGERAIL

TEST 287 72 MPH, 25°, 4830 LB. DODGE
DUMMY RESTRAINT - LAP BELT

ACCELEROMETER LOCATION - DUMMYS CHEST
DATA FILTERED AT 100 HERTZ

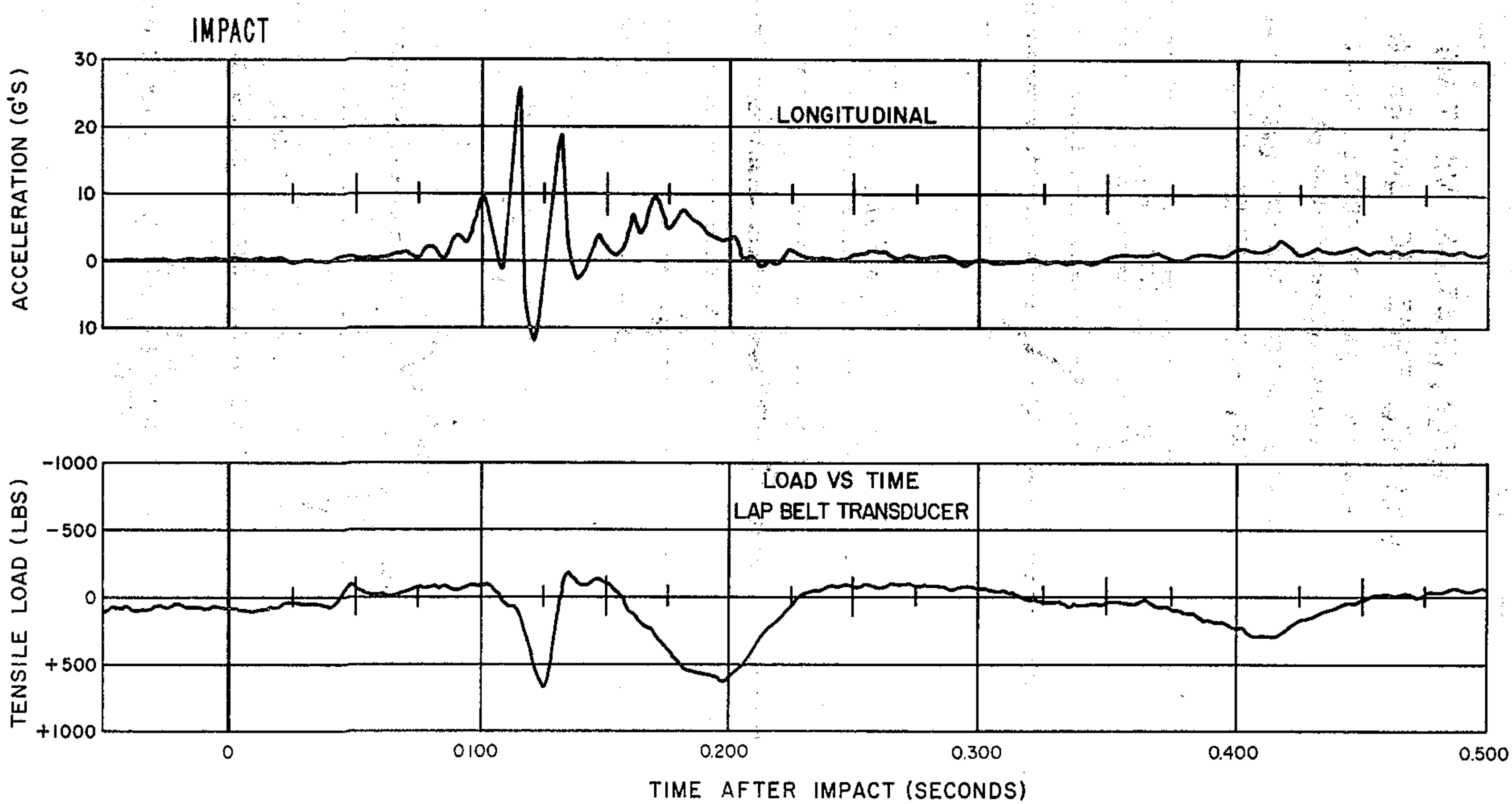


FIGURE 8-A
ACCELEROMETER RECORDS- DUMMYS CHEST
TEST 287

ACCELERATION VS TIME

MODIFIED TYPE 20 BRIDGERAIL

TEST 287 72 MPH, 25°, 4830 LB. DODGE
DUMMY RESTRAINT - LAP BELT

ACCELEROMETER LOCATION - VEHICLE FLOOR
DATA FILTERED AT 100 HERTZ

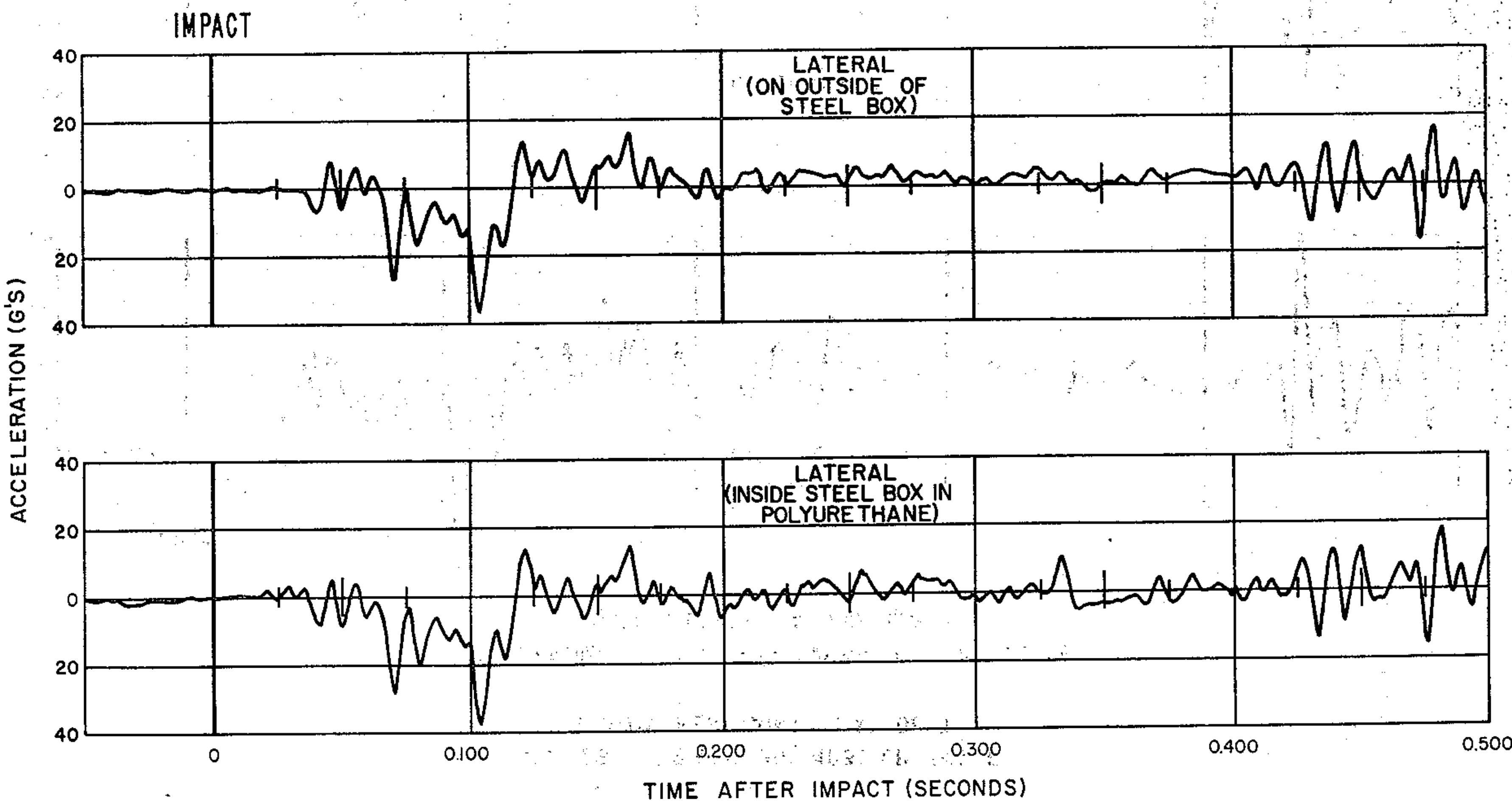


FIGURE 9-A
ACCELEROMETER RECORDS - VEHICLE FLOOR
TEST 287

ACCELERATION VS TIME

MODIFIED TYPE 20 BRIDGERAIL

TEST 287 72 MPH, 25°, 4830 LB. DODGE
DUMMY RESTRAINT - LAP BELT

ACCELEROMETER LOCATION-VEHICLE FLOOR AT C.G.
DATA FILTERED AT 100 HERTZ

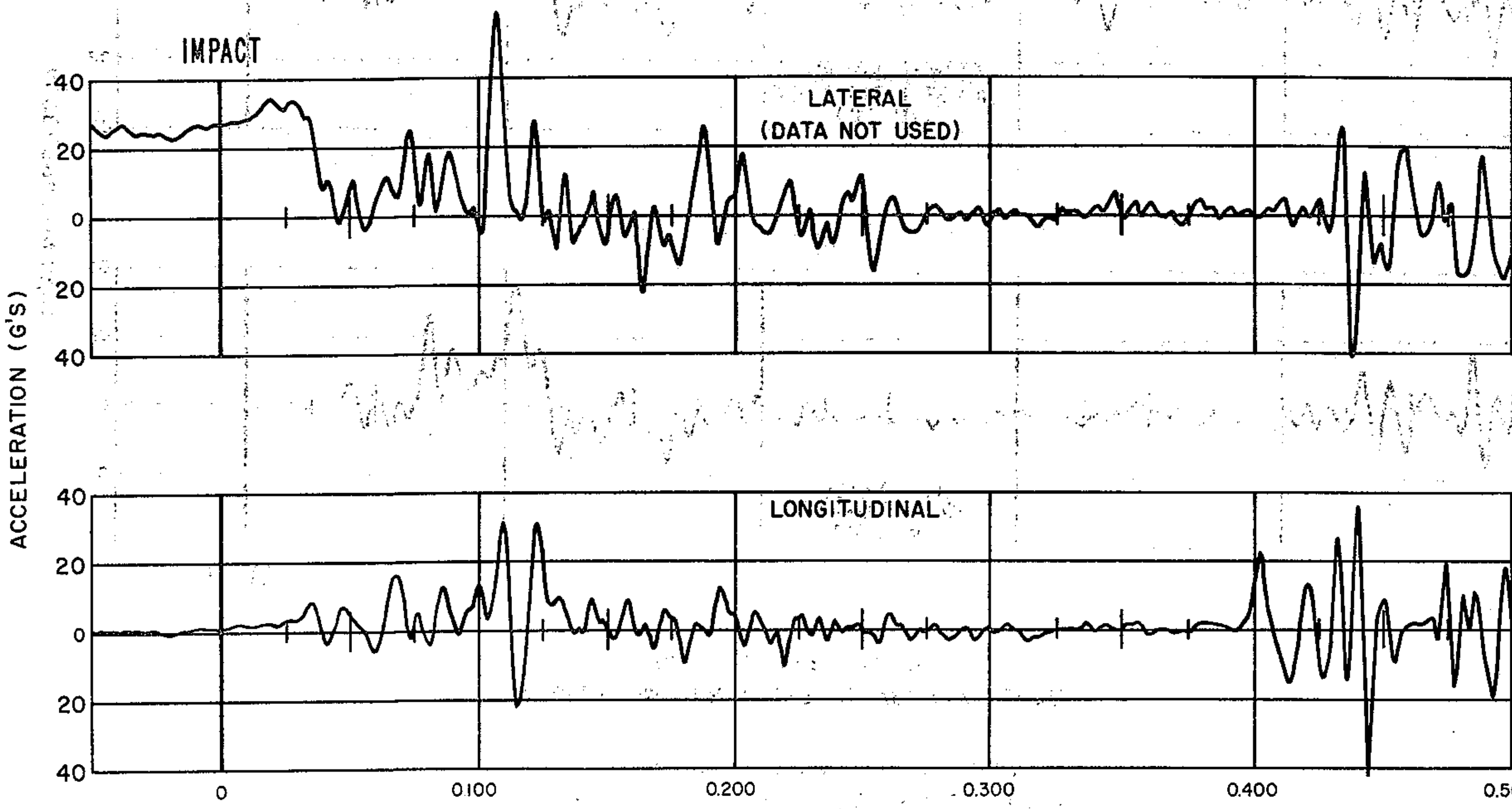


FIGURE 10-A
ACCELEROMETER RECORDS - VEHICLE C.G.
TEST 287

VEHICLE IMPACTOGRAPH DATA

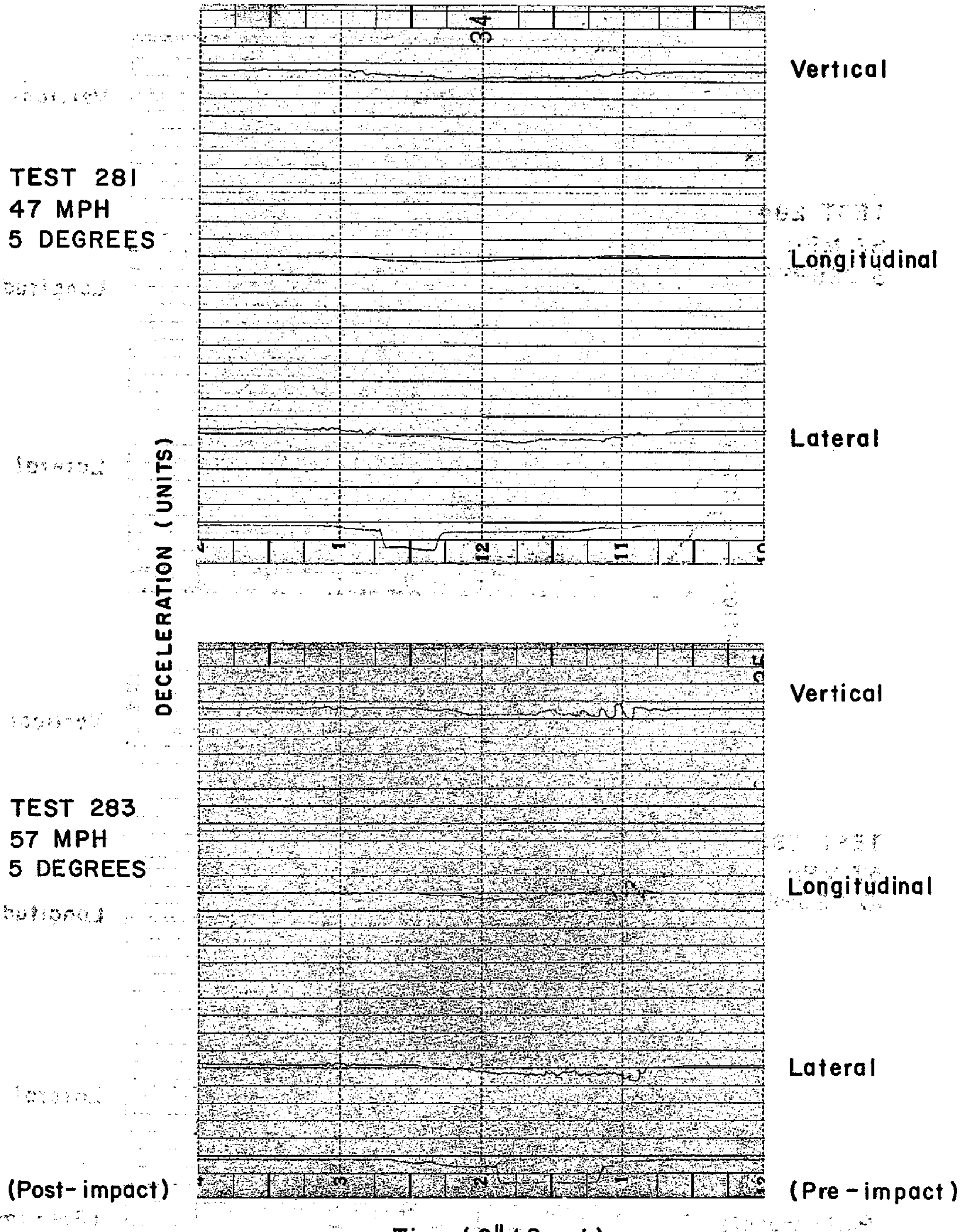


FIGURE 11-A
VEHICLE IMPACTOGRAPH DATA
TESTS 281-283

VEHICLE IMPACTOGRAPH DATA

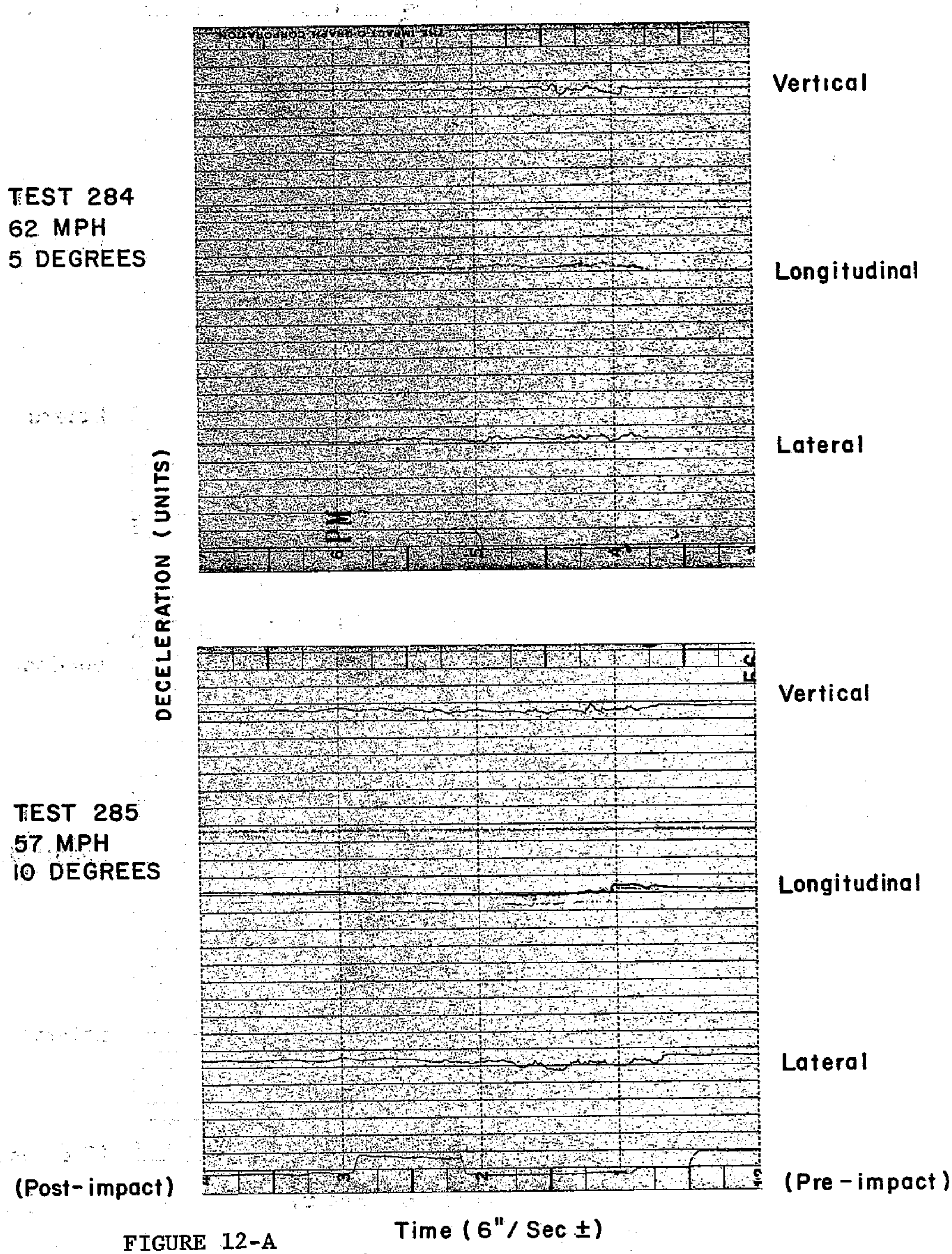


FIGURE 12-A
VEHICLE IMPACTOGRAPH DATA
TESTS 284-285

VEHICLE IMPACTOGRAPH DATA

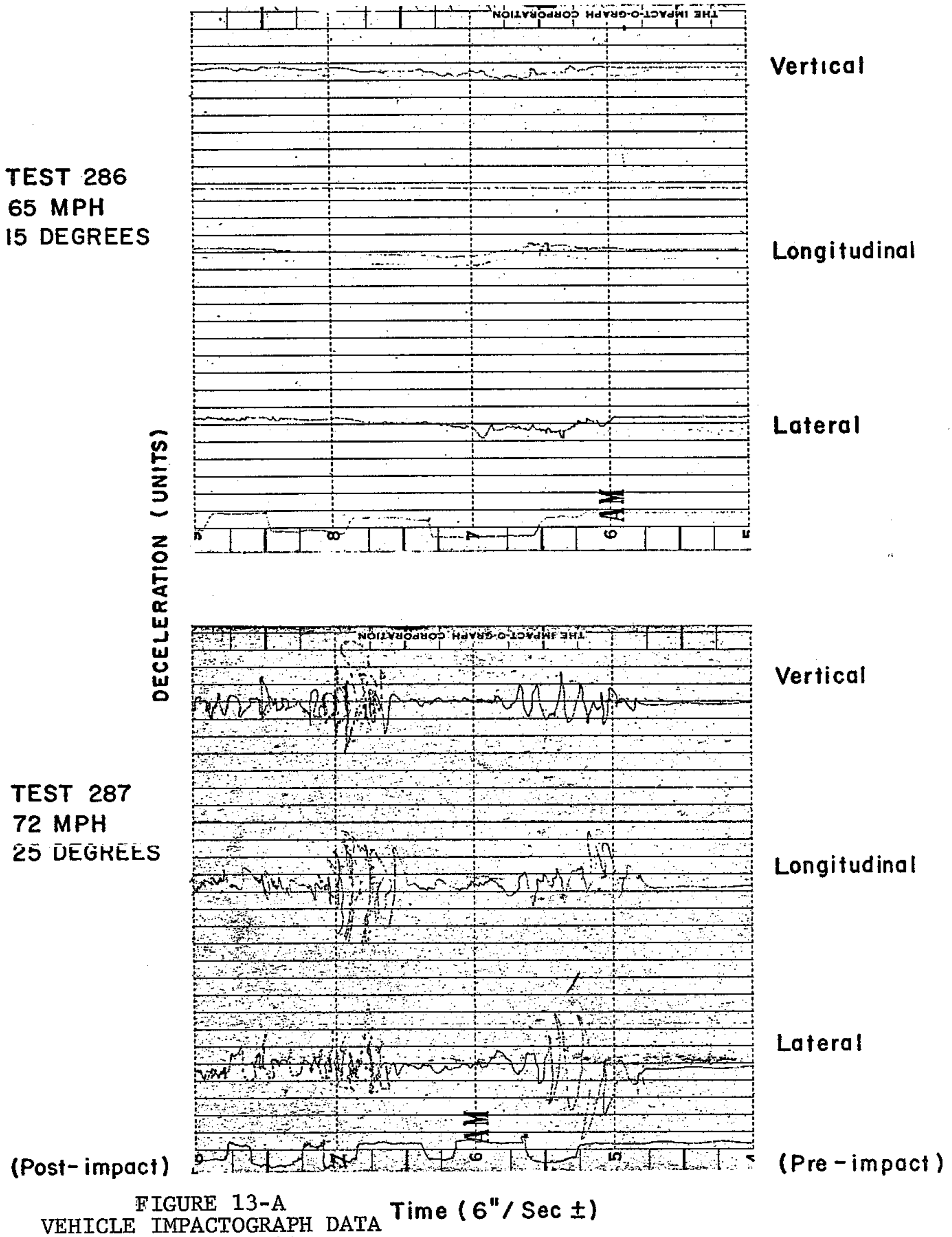


FIGURE 13-A
VEHICLE IMPACTOGRAPH DATA
TESTS 286-287